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Energy and Mines
Geological Services**



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Geochemistry of Metavolcanic Rocks in the Lynn Lake Belt

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INTRODUCTION

The Lynn Lake greenstone belt is one of three Proterozoic metavolcanic belts occurring in the Churchill Structural Province in Manitoba (Fig. 1). The metavolcanic rocks described in this report were mapped at a scale of 1:50 000 between 1976 and 1978 and represent the westernmost part of the greenstone belt in Manitoba. Gilbert et al. (1980) describe the primary structures, petrography and stratigraphic relationships of the volcanic and volcanoclastic rocks in the area. This report goes on to document major, trace and rare earth element compositions of the various rock units, and integrates the chemistry and stratigraphy in order to outline the geochemical evolution of the belt. A comparison is also made between the Lynn Lake metavolcanic rocks and those of Archean and Cenozoic volcanic terranes in an attempt to gain more information on the tectonic environment in which this Proterozoic sequence was emplaced.

Mineral deposits in the area, such as the Fox Lake Cu-Zn deposit and the Agassiz stratabound Au-Ag deposit, can be fitted into the chemo-stratigraphic model of the belt. It is also demonstrated that the apparent

relationship between Archean Cu-Zn ore deposits and felsic rocks that display a diagnostic rare earth element abundance pattern is not present in this Proterozoic belt.

Although the Lynn Lake metavolcanic rocks superficially resemble those of Archean greenstone belts, significant stratigraphic, lithologic and geochemical differences are evident. These differences are consistent with current models which propose that volcanic and tectonic regimes evolved continuously during the early Precambrian. Trace and rare earth element abundances in the mafic volcanic rocks provide insight into the composition of their mantle source and are a key to significant trends in the geochemical evolution of the Proterozoic mantle.

The Lynn Lake metavolcanic sequence resembles Cenozoic island arc assemblages in lithologic make-up, relationships of volcanic to sedimentary units, overall chemo-stratigraphy, and trace and rare earth element abundances. These similarities strongly suggest that the Lynn Lake greenstone belt represents an early Proterozoic intra-oceanic volcanic arc related to a consumptive plate margin.

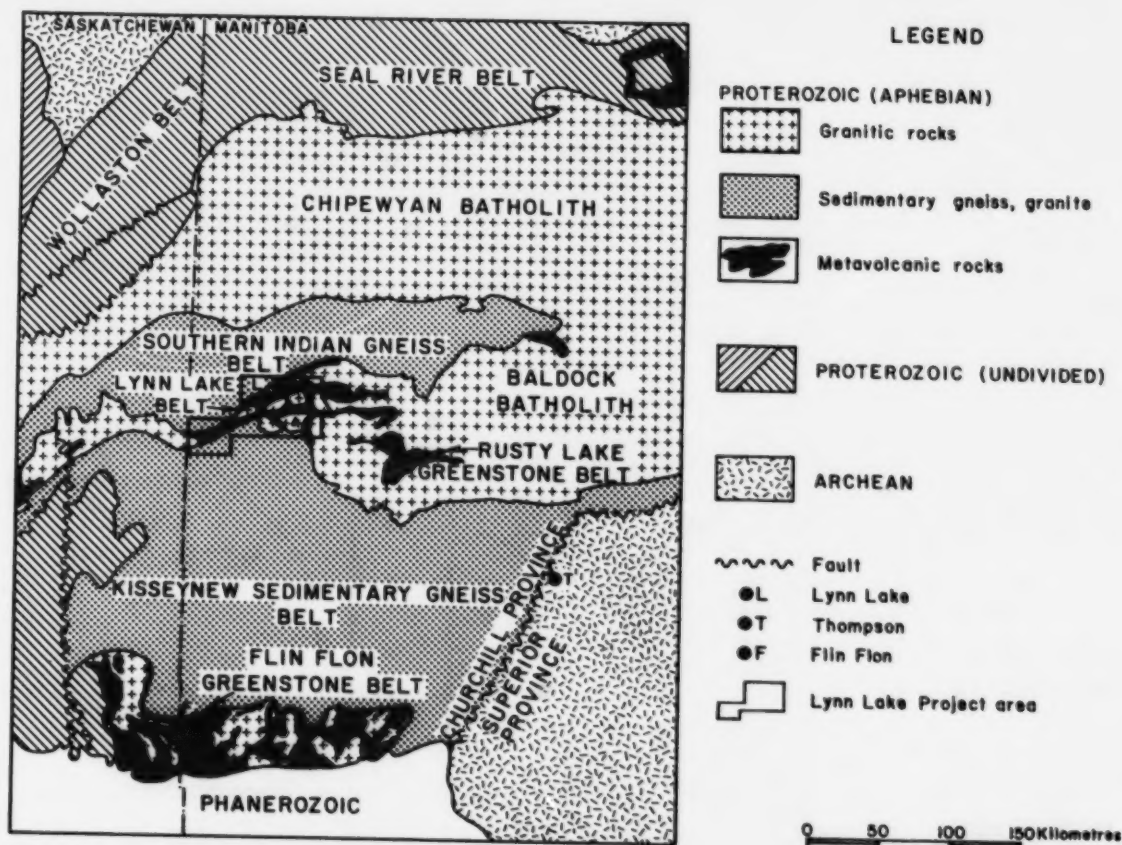


Figure 1: Location and structural setting of the Lynn Lake greenstone belt.

GENERAL GEOLOGY OF THE LYNN LAKE BELT

REGIONAL SETTING

The Lynn Lake region lies within the Churchill Structural Province and encompasses three major Aphebian lithostructural domains. From north to south these are:

- (1) the southern margin of the Southern Indian gneiss belt;
- (2) the Lynn Lake greenstone belt and associated intrusions;
- (3) the northern margin of the Kisseynew sedimentary gneiss belt (Fig. 1, 2 and 3).

The Southern Indian gneiss belt flanks the Lynn Lake greenstone belt to the north. The belt comprises paragneiss, amphibolite, migmatite and abundant intrusive rocks. The metasedimentary rocks were derived from greywacke-siltstone turbidites and are overlain by a thin unit of mafic tuff. The age of these rocks is uncertain but they are generally considered to be stratigraphically equivalent to the Wasekwan Group. However, Rb/Sr metamorphic ages (Clark, 1984) indicate that they could be older than the adjacent part of the Wasekwan Group. They are separated from Wasekwan Group volcanic rocks by a conglomerate formation which is interpreted to occupy a synclinal structure.

The Lynn Lake greenstone belt, comprising metamorphosed volcanic, sedimentary and plutonic rocks, extends 130 km from Laurie Lake in the west to Magrath Lake in the east. The belt has a maximum width of 60 km and is part of a major lithostructural domain, underlain by largely granitic rocks and greenstone, that extends southwest to La Ronge, Saskatchewan (Johnston, 1979). Lewry et al. (1981) refer to this as the Rottenstone-La Ronge Magmatic Belt. Rocks in the Lynn Lake belt have an early Proterozoic (Aphebian) age of deposition, intrusion and metamorphism (Clark, 1980; Baldwin et al., 1985). The volcanic and volcanoclastic rocks belong to the Wasekwan Group (Bateman, 1945; Campbell, 1969). They have been intruded by subvolcanic plugs, and subsequently folded, faulted and intruded by larger mafic and felsic plutons. Unconformably overlying these rocks are sandstone and conglomerate of the Sickle Group (Norman, 1933; Campbell, 1969). Regional upper greenschist to upper amphibolite facies metamorphism and further deformation and plutonism took place after deposition of the Sickle Group.

The Kisseynew belt flanks the Lynn Lake greenstone belt to the south; it is composed of paragneiss, amphibolite and migmatite derived from Aphebian (Clark, 1974) sedimentary and minor volcanic strata. This belt and adjacent portions of the greenstone terrane have

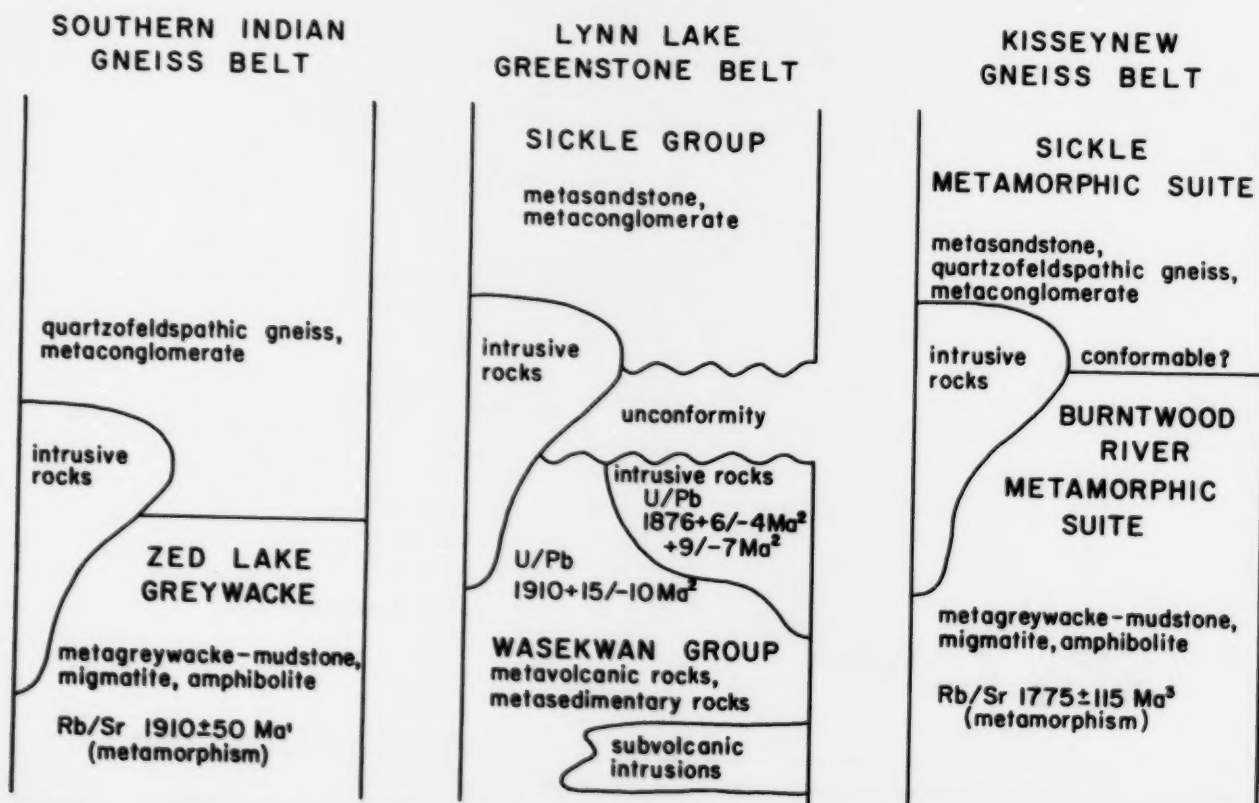


Figure 2: Stratigraphic outline for the Lynn Lake region. Age determinations from: 1 — Clark (1984), 2 — Baldwin et al. (1985), 3 — Clark et al. (1974).

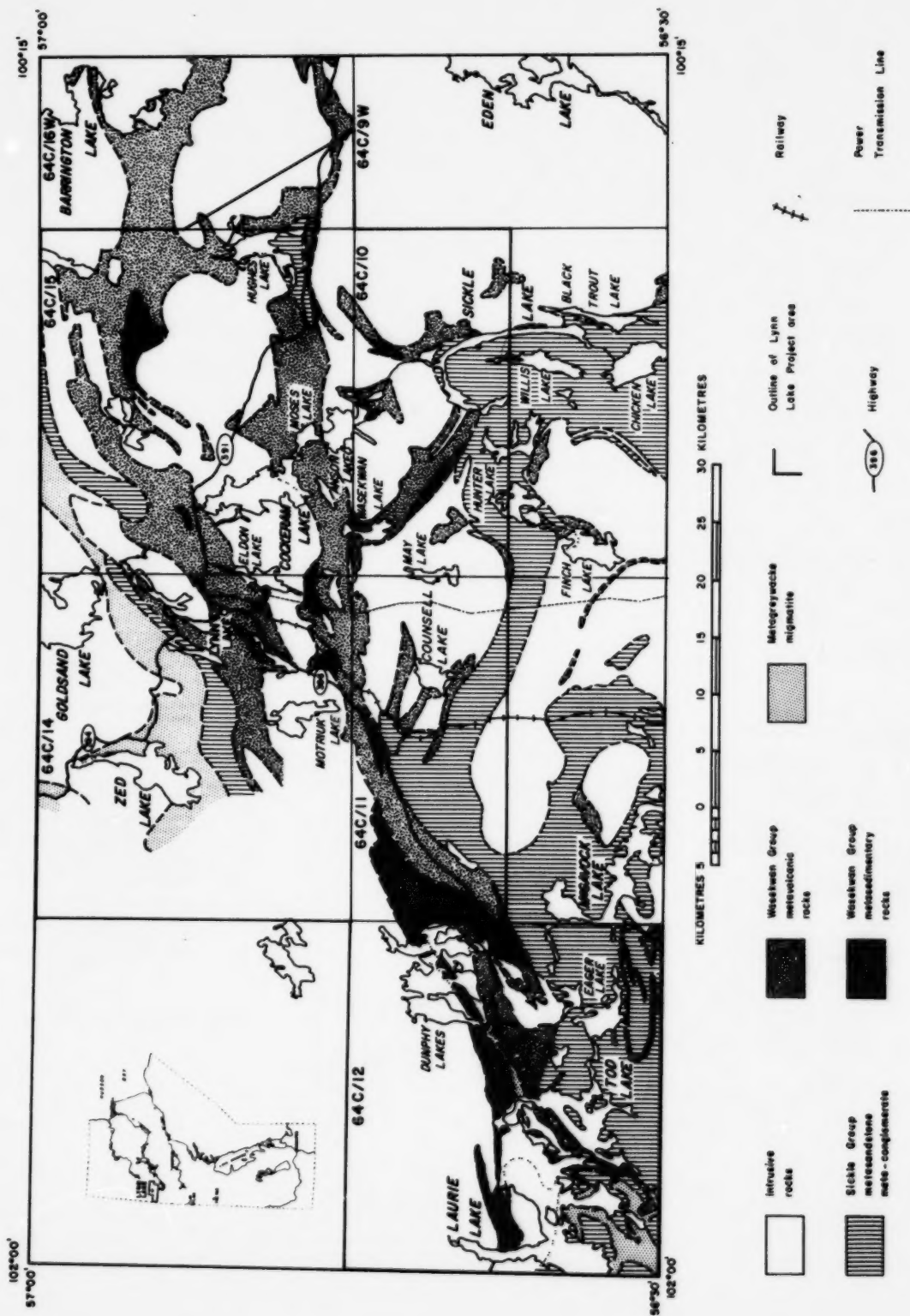


Figure 3: Generalized geology of the Lynn Lake belt.

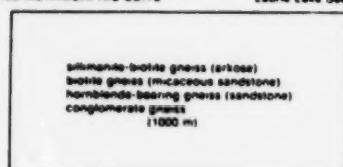
Table 1:
a) Stratigraphic sections and correlat

LAURIE LAKE — DUNPHY LAKES AREA

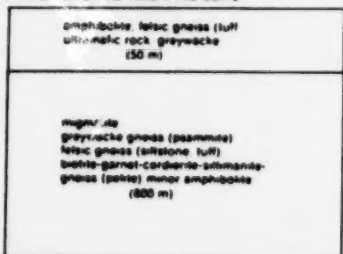
FOX MINE — GEMMELL LAKE AREA

COCK

SICKLE METAMORPHIC SUITE Laurie Lake Section

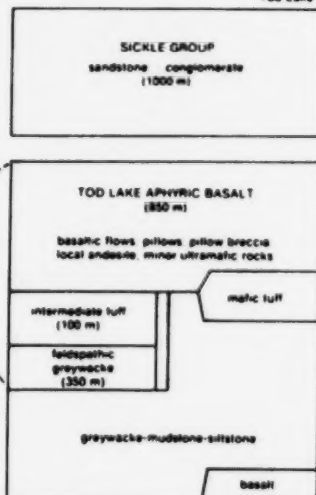


BURNTWOOD RIVER METAMORPHIC SUITE



Laurie Lake Section

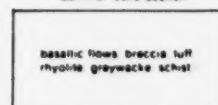
Tod Lake Section



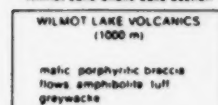
FOX MINE — GEMMELL LAKE AREA

COCK

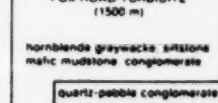
Gemmell Lake Section



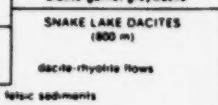
Wilmot Lake-Snake Lake Section



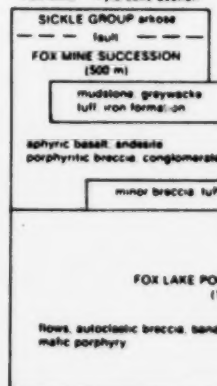
FOX ROAD TURBIDITE



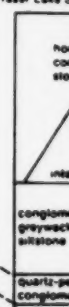
SHAKE LAKE DACITES



Fox Mine - Pyta Lake Section



Fraser Lake S-



flows,
tuff
intercal
basalt
silt

Table 1:
ages and correlation in the Southern Belt.

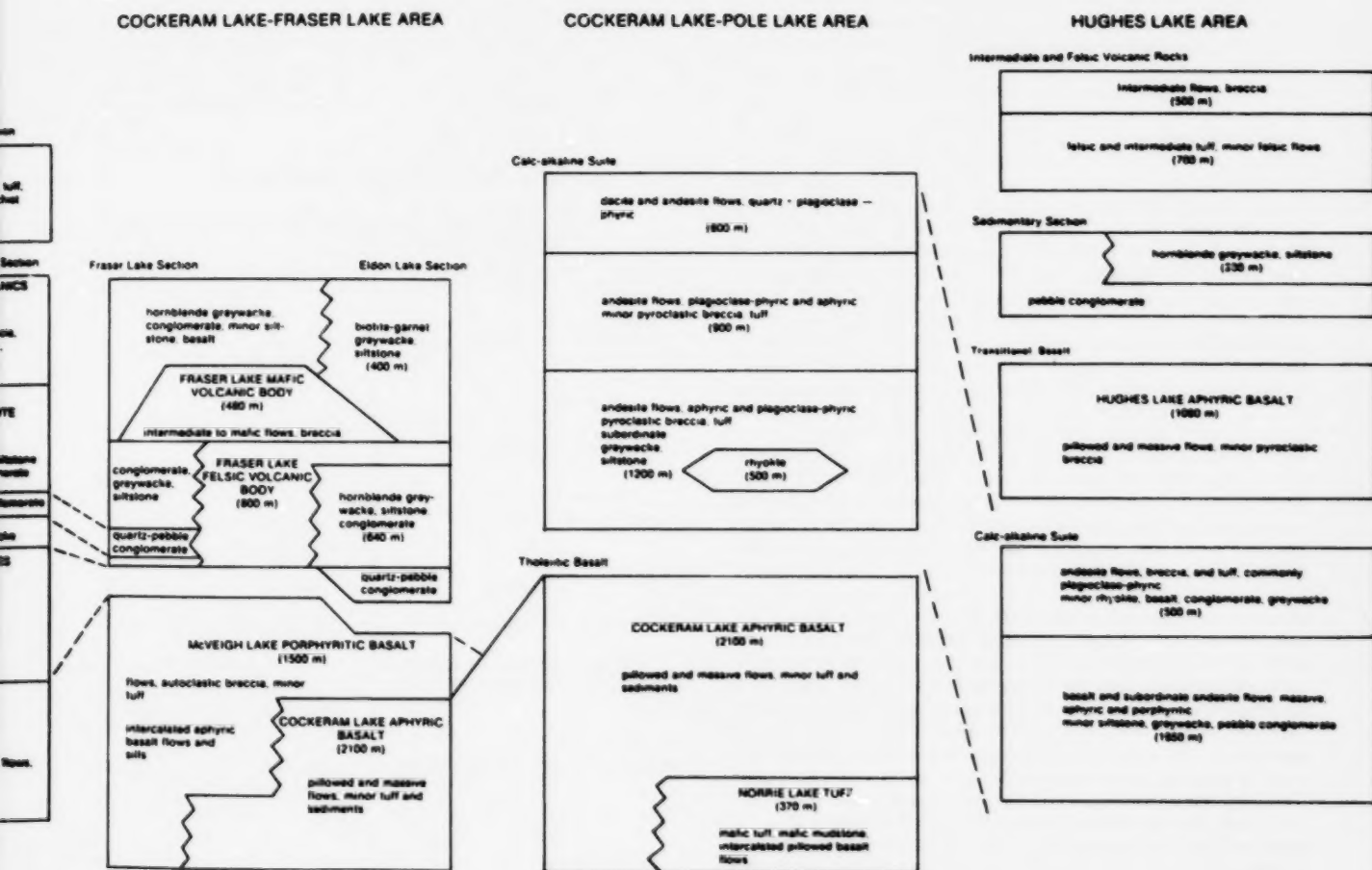
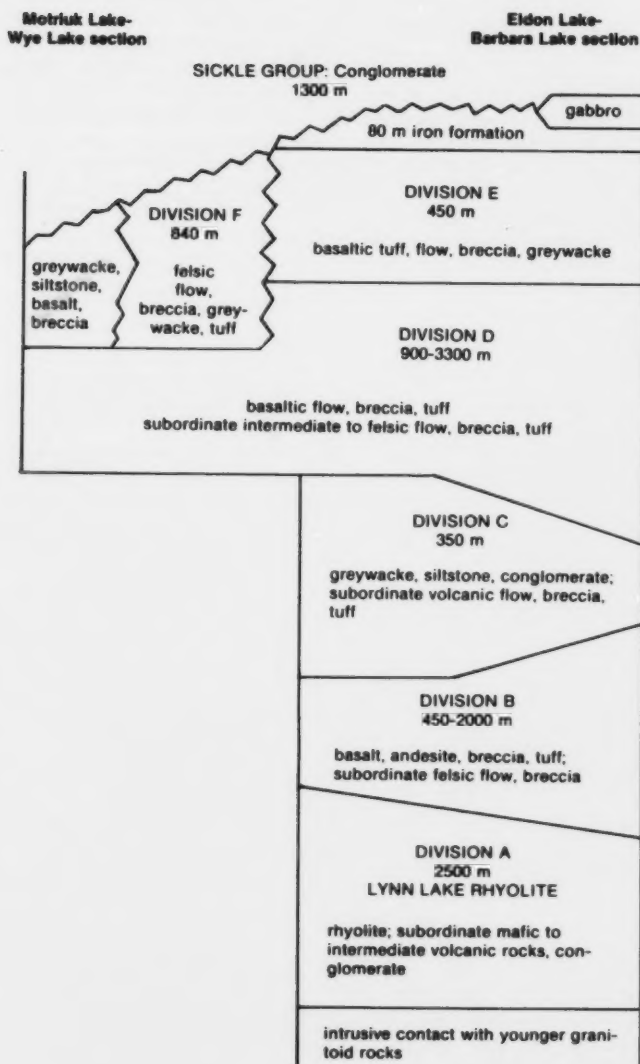


TABLE 1: b) Stratigraphic section in the Northern Belt



undergone upper amphibolite facies metamorphism and polyphase deformation. The sedimentary succession consists of two distinct sequences: (1) the Burntwood River Metamorphic Suite and (2) the overlying Sickle Metamorphic Suite (terminology modified after McRitchie, 1974; Gilbert et al., 1980). The Burntwood River Metamorphic Suite is composed of quartzofeldspathic paragneiss and migmatite derived from greywacke-mudstone turbidites, and thin, conformably overlying amphibolite derived from mafic volcanic and volcanoclastic strata. The sediments were probably deposited contemporaneously with the volcanic and sedimentary rocks of the Amisk Group at Flin Flon (Bailes, 1971; McRitchie, 1974). The Sickle Metamorphic Suite comprises quartz- and

feldspar-rich paragneiss derived from lithic sandstone, calcareous sandstone, arkose and conglomerate which conformably overlie the Burntwood River greywacke-derived gneisses. The Sickle Metamorphic Suite is stratigraphically equivalent to the Sickle Group in the Lynn Lake greenstone belt.

WASEKWAN GROUP

The Wasekwan Group, which is the focus of this report, consists of volcanic and volcanoclastic sedimentary rocks which occupy structural belts separated by large oval tonalite-granodiorite plutons. Detailed descriptions and interpretation of the volcanic rocks, and their stratigraphic relationships, have been published in a companion paper (Gilbert et al., 1980).

Variations in volcanic stratigraphy occur laterally, between partly overlapping volcanic units, and across strike, between separate structural belts. Consequently a general correlation of all units in the Lynn Lake area cannot be made with certainty. The most extensive stratigraphic successions define two northeast-trending structural belts, separated by a chain of tonalite plutons: these are the **Northern Belt** between Motriuk Lake and Eagle Lake, and the **Southern Belt** between Fox Mine and Hughes Lake (Figs. 3 and 4). Smaller contiguous and isolated areas of greenstone occur to the south, in the predominantly granitoid terrane between Counsell Lake and Sickle Lake.

The Southern Belt (Table 1) contains what are interpreted to be the oldest rocks in the Lynn Lake area. These rocks comprise over 2000 m of aphyric flows (Cockeram Lake basalt) and pyroxene-phyric flows and breccias (McVeigh Lake basalt). Somewhat more magnesian porphyritic basalt at the base of the Wasekwan succession south of Fox Mine (Fox Lake basalt) is tentatively correlated with the McVeigh Lake basalt. These aphyric and porphyritic basalts are interpreted as at least two separate but partially overlapping shield volcanoes, which together form an extensive mafic "platform" in the Southern Belt.

The basalts are overlain by discontinuous units of sedimentary rocks, including up to 1500 m of turbidite (Fox Road turbidite) in the western part of the Southern Belt. Elsewhere the basalts are overlain by a variety of mafic, intermediate and felsic volcanic complexes. In the Hughes Lake area more than 2500 m of calc-alkaline rocks (Hughes Lake calc-alkaline suite) overlie the Cockeram Lake basalt; the calc-alkaline sequence is in turn overlain by aphyric transitional basalt (Hughes Lake aphyric basalt).

A heterogeneous volcanic and sedimentary succession extends from McVeigh Lake southwest for 30 km to the area west of Wilmot Lake. In the Gemmell Lake area, near the probable stratigraphic top of the succession, mafic rocks are intercalated with felsic volcanic rocks, tuffs, fine grained sedimentary rocks and iron formation. The heterogeneous volcano-sedimentary succession in the Wilmot Lake-Gemmell Lake area, the calc-alkaline rocks in the Hughes Lake area, and a thin, slightly more mafic succession at Fox Mine, all occupy a similar stratigraphic position relative to the underlying aphyric and porphyritic basalt "platform".

The Northern Belt consists largely of mafic volcanic rocks intercalated with subordinate felsic and local intermediate units. The mafic part of the sequence extends from an area north of Motriuk Lake, 70 km eastward to Barrington Lake. The Northern Belt is characterized by the presence and abundance of highly aluminous, commonly plagioclase-phyric basalt flows and breccias. These rocks are intercalated with flows with "normal" alumina contents. The stratigraphic sequence is divided into five major components (Table 1) comprising, from oldest to youngest: rhyolite pyroclastic rocks and flows (Division A), high-alumina basalt, basalt, andesite and rhyolite (Division B), dominantly turbiditic sedimentary rocks (Division C), more primitive high-alumina basalt, basalt, and high-magnesia basalt (Division D), and basaltic tuff and volcanogenic sediments (Division E). Stratigraphic correlation between the Northern and Southern Belts suggests that the high-alumina suite overlies the Southern Belt section.

METAMORPHISM

The grade of metamorphism of Wasekwan Group rocks ranges from medium to high. Middle amphibolite facies assemblages characterize most rocks of the Lynn Lake belt. Upper greenschist facies assemblages occur in the Cartwright Lake-Hughes Lake area (Fig. 4) and locally in the Northern Belt. Upper amphibolite facies assemblages are restricted mainly to the Fox Mine area at the west end of the belt.

Greenschist facies assemblages in andesites and basalts of the Cartwright Lake-Hughes Lake area are characterized by albite, epidote, pale green actinolite and/or biotite, chlorite, leucoxene, quartz and carbonate. At slightly higher grade, to the west at Moses Lake, equivalent rocks contain greenschist-amphibolite transition facies assemblages (dark green hornblende, albite, epidote, and minor quartz, magnetite and biotite). Lowermost amphibolite facies assemblages, in rocks west of Moses Lake, are mineralogically identical except that their plagioclase compositions are in the oligoclase-andesine range. Greenschist facies assemblages of pale green chlorite, tremolite, epidote, clinozoisite,

sphene, albite and carbonate are only locally present in the mafic rocks of the Northern Belt.

Lower- to middle-amphibolite facies assemblages occur throughout the Northern Belt, in the western part of the Southern Belt, and in the Miskwa Lake and Keewatin River belts (Fig. 4). Basaltic rocks are characterized by assemblages including green hornblende and/or cummingtonite, oligoclase or andesine, epidote, biotite, quartz and sphene. Sedimentary rocks in the Eldon Lake area, in the Miskwa Lake belt, and in the Keewatin River belt contain staurolite-free amphibolite facies assemblages, whereas staurolite is relatively common in the Southern Belt southwest of Nail Lake. Relicts of andalusite and kyanite occur within cordierite, west of Boileau Lake.

Upper amphibolite facies mineral assemblages are developed in the western part of the Lynn Lake belt. Minerals occurring in altered dacite and sedimentary rocks at Snake Lake comprise assemblages that include quartz, plagioclase, cordierite, anthophyllite, staurolite, garnet, biotite, sillimanite and magnetite. Metamorphic K-feldspar occurs in greywacke north of Hatchet Lake.

GEOCHEMISTRY: INTRODUCTION

The basic objectives of this geochemical study of Wasekwan Group volcanic rocks are:

- (1) to document the compositional variation between and within map units;
- (2) to determine whether the separate lithostratigraphic units (Table 1) can be distinguished chemically;
- (3) to determine the chemical evolution of the Lynn Lake belt, i.e., integrate stratigraphy and chemistry;
- (4) to outline the petrogenesis of the major rock units and the volcanic pile as a whole;
- (5) to test whether volcanic rocks containing known mineral deposits can be distinguished from barren rocks by their major and trace element chemistry;
- (6) to highlight the similarities and differences between Lynn Lake chemistry and certain Archean and Cenozoic volcanic suites; and
- (7) to determine the tectonic environment in which the Lynn Lake volcanic rocks were deposited.

Table A1 in the Appendix lists the analyses by region and lithologic or lithostratigraphic unit. The overall regional subdivision is as follows: McVeigh Lake-Sickle Lake-Hughes Lake area (analyses 1-61), Northern

Belt (analyses 62-101), Gemmell Lake-McVeigh Lake area (analyses 102-113), and Fox Mine-Wilmot Lake area (analyses 114-195). Locations of the analyzed samples are shown on Figure 4 (in pocket) which also serves as a simplified geological map of the area.

Analyzed rocks are predominantly grab samples collected during routine mapping, and are generally representative of the outcrop. Rocks that were obviously altered, weathered or veined were avoided. In some areas sampling was conducted specifically for analysis, to document compositional variation through a single flow or series of flows, or through a specific stratigraphic section. All of the major rock units are represented by several analyses, and most of the units are represented by at least one analysis.

Nomenclature for the metavolcanic rocks is necessarily simple and is based on SiO_2 content (by weight): basalt = 46-54 per cent, andesite = 54-62 per cent, dacite = 62-70 per cent, rhyolite = 70-78 per cent. The SiO_2 class limits were determined by adding and subtracting one standard deviation from the average SiO_2 contents listed for these rocks by Le Maitre (1976). Classification as to magma series (tholeiitic, calc-alkali and alkali-olivine basalt) is generally after Miyashiro (1974) and Irvine and Baragar (1971). High-alumina basalts are arbitrarily defined as those containing more than 17 per cent Al_2O_3 .

ALTERATION

Most of the Wasekwan Group in the Lynn Lake area was originally deposited in a subaqueous environment. The volcanic and volcanoclastic rocks were subsequently folded, faulted and subjected to upper greenschist to upper amphibolite facies metamorphism. Consequently all of the rocks can be expected to have undergone some degree of alteration from their primary compositions. The fact that all of the rocks are to some extent altered is important because the criteria used to distinguish different magma types are based, for the most part, on data from relatively fresh Cenozoic volcanic rocks. In the following sections the types of alteration that can be expected to have affected the Wasekwan Group volcanic rocks, and the probable mobilities of major and trace elements, are briefly reviewed.

TYPES OF ALTERATION

Three major types of alteration have contributed to changes in the primary compositions of Wasekwan Group volcanic rocks; these are (1) low temperature sea-floor alteration, (2) high temperature hydrothermal alteration, and (3) alteration associated with regional greenschist to amphibolite facies metamorphism. Quantitative unravelling of the superimposed alteration events is beyond the scope of this report, but the qualitative changes associated with each of the three alteration events are listed below.

(1) Low temperature (less than 200°C) alteration and seafloor weathering (halmyrolysis) of basalt pillows involves hydration and palagonitization of glassy pillow rims and production of clay and zeolites in the crystalline interiors (Scott and Hajash, 1976); "old" pillow basalts from ocean ridges have highly altered rims and less altered interiors. Most studies of low temperature chemical exchange between seawater and basaltic lavas indicate a net addition to basalt in K, Fe, P and Ti, and a net loss from basalt in Si, Ca, Mg and Na (Cann, 1969; Miyashiro et al., 1969; Hart, 1970; Hart and Nalwalk, 1970; Melson, 1973; Thompson, 1973; Melson and Thompson, 1973; Hart, 1973; Shido et al., 1974; Scott and Hajash, 1976). Hart (1973) notes an increase in Ba, Rb, Sr, V, Zr and Rb/Sr ratio with alteration and a decrease in Co, Cr and Ni.

(2) High temperature hydrothermal alteration processes include deuteric alteration occurring toward the end of crystallization, penetration of seawater along cooling cracks to the hot interior of pillows or flows, trapping and heating of seawater in interstices within pillowed flows, and deep circulation of seawater along fractures in newly formed hot lithosphere (Scott and Hajash, 1976). There is an extensive body of literature which documents high-temperature hydrothermal alteration in both natural and experimental systems (e.g. Scott and Hajash, 1976; Humphris and Thompson, 1978a,b; Mottl, 1983; and references therein). Much of the information available is concerned with alteration of basalts within hydrothermal systems at mid-ocean ridges, and the experiments which predicted the chemistry of high temperature solutions in these systems. High temperature hydrothermal or hydrous metamorphic reactions (approximately 200–450°C) in natural basalts result in the uptake of Mg from seawater and the loss of Ca from basalt on a mole-for-mole basis. There is a net addition of Na to basalt at water-rock ratios less than 10 and a net loss of Na at higher ratios. Silica is generally leached from basalt during alteration but a considerable portion is redistributed within the basaltic pile. There are no consistent trends for Fe, K, P and Mn; Ti displays an increase in altered basalts. Cu, Zn, Sr, Ag, Au, W, Ni and Co are all leached from basalt. A recent review of experimental results (Mottl, 1983) indicates that the most characteristic feature of basalt-seawater interaction at high temperatures is the rapid removal of Mg^{2+} from seawater into secondary smectite, chlorite,

tremolite-actinolite, or talc in metabasalt. Uptake of Mg^{2+} is balanced by leaching of Ca^{2+} from the rock. Sodium is removed from seawater at water:rock ratios less than 5; at a ratio of 10 Na⁺ is removed from seawater at 350°C but leached from the rock at 300°C; at ratios above 10, Na⁺ is leached from the rock along with Ca^{2+} . At 150°C and above, K⁺ is uniformly leached from the rock.

(3) extensive chemical adjustment during regional burial metamorphism has been documented by Smith (1968), Smith and Smith (1976), and Reed and Morgan (1971). These authors have described the chemical variability in basaltic rocks containing mesoscopic heterogeneities of metamorphic origin, and have shown that Ca and Sr are enriched in epidotized domains whereas Na, Fe, and K are depleted in epidotes and are enriched in adjacent "albitized" or "spilitic" basalt. Concentrations of Ti, Zr, Y and P are relatively constant. Condie et al. (1977) show that, relative to less altered portions of flows, epidotized Archean tholeiites are enriched in Au, As, Sb, Sr, Fe^{3+} , Ca, Br, Ga and U, and are depleted in H_2O , Na, Mg, Fe^{2+} , K, Rb, Ba, Si, Ti, P, Ni, Cs, Zn, Nb, Cu, Zr and Co. A parallel enrichment/depletion pattern occurs in epidotized Proterozoic basalts from Flin Flon, Manitoba (Bailes and Syme, unpublished data): relative to less altered portions of flows, epidotes are enriched in Ca, Sr and Fe^{3+} , and are depleted in Na, K, Rb, Fe^{2+} , Ba, Zn, Si and Mg (Fig. 5). Al and Ti show no consistent trends and Ni, Cr and P are commonly unchanged.

From a study of Archean tholeiitic and calc-alkaline pillows, Gétinas et al. (1982) concluded that the measured FeO^*/MgO ratios commonly reflect the primary values. They observed that Ca leaching from interiors of pillows is coupled with either Fe or Mg substitution, reflecting low temperature and high temperature alteration, respectively. Luden et al. (1982) have shown, in the same suite of Archean pillows, that for low grade metamorphism Zr, Y, Ti and REE are immobile, whereas Rb, Ba, and, to a lesser extent, Sr are mobile at all levels of alteration.

* $FeO^* = FeO + 0.9 Fe_2O_3$, i.e. total iron expressed as FeO .

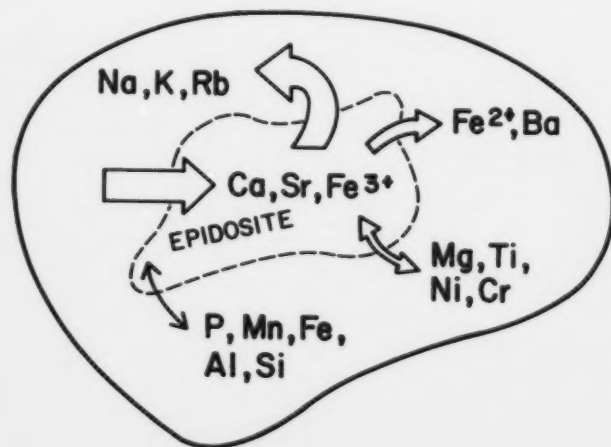


Figure 5:

Element mobility during epidotization of basaltic andesite pillow, Amisk Group, Flin Flon greenstone belt. Relative mobilities shown by width of arrows.

WASEKWAN GROUP ALTERATION

In Wasekwan Group rocks chemical adjustment during sea-floor alteration and/or regional metamorphism has resulted in the ubiquitous development of Ca-rich metadomains (epidosites) which cut across primary igneous structures. Alteration of this type is most common in mafic and intermediate rocks but also occurs locally in felsic rocks. Consequently the epidote-alteration effects noted above are likely to be present throughout the area. Analyzed samples are generally of the "unepidotized" material in flows that contain epidosite domains, but Reed and Morgan (1971) have shown that this type of sampling bias results, for basalts, in the collection of "spilitic" (Na-metasomatised) compositions. A calculated bulk composition, including the epidosite, is in fact closer to the primary composition of the lava (Reed and Morgan, 1971; Smith, 1968). For such a calculation to be possible the exact volumetric proportion of epidosite must be determined at each sample locality, and the epidosite domains must be analyzed. In the Lynn Lake project the emphasis on more regional data collection precluded such detailed study. Plots of Wasekwan Group analyses on an igneous spectrum diagram (Hughes, 1972) and on a normative An-Ab-Or diagram (Irvine and Baragar, 1971) show that many of the rocks have compositions which plot outside the fields of "normal" igneous rocks (Figs. 6 and 7). Mobility of Na, K and Ca has resulted in weak to strong Na enrichment in the relatively unepidotized portions of the flows.

Analyses which plot within the fields of "normal" igneous rocks on Figures 6 and 7 are not necessarily primary unaltered compositions. It is much more likely that Na, K and Ca adjustments have occurred, but the adjustments were either minor or combined in a way that kept the composition within the "normal" field. Given the ample outcrop and petrographic evidence of mobility in alkalis and Ca, it is misleading to use plots such as these to discriminate between altered and unaltered rocks. The plots are useful to document varying severity and styles of

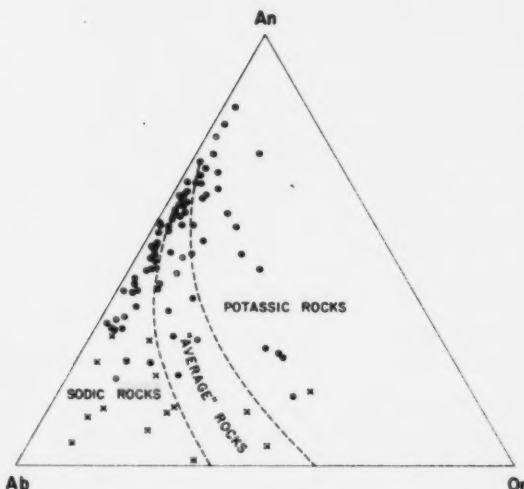


Figure 7:

An-Ab-Or plot of Wasekwan Group rocks, showing boundaries for distinguishing sodic, "average", and potassic subalkaline rocks (Irvine and Baragar, 1971). Normative plagioclase composition is strongly dependent on Na_2O and K_2O , and is consequently sensitive to changes produced by alteration and metamorphism. Symbols as for Fig. 6.

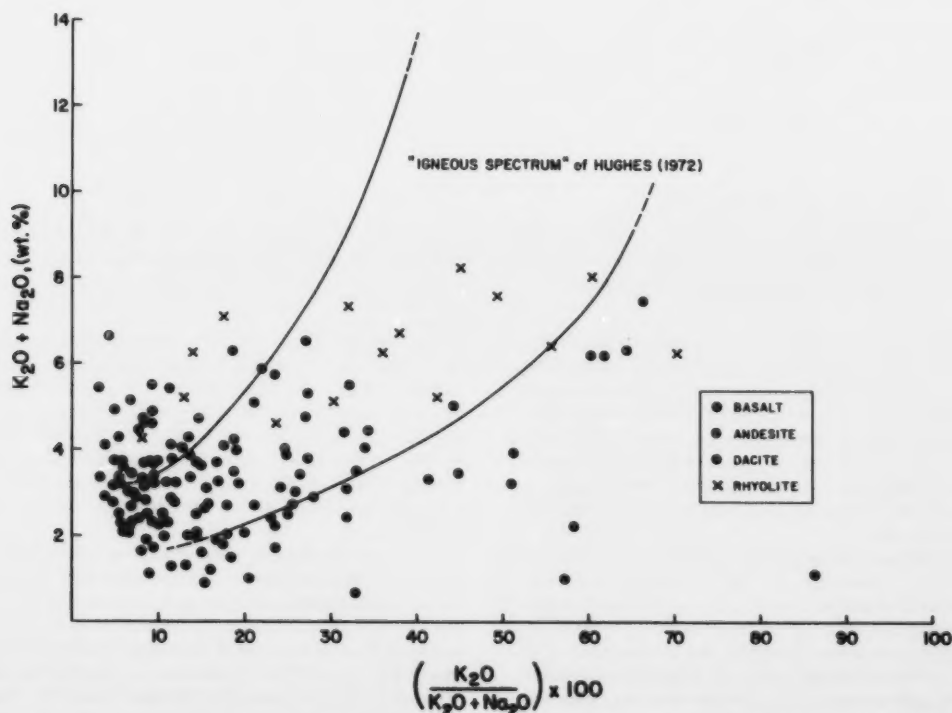


Figure 6:

$\text{K}_2\text{O} + \text{Na}_2\text{O}$ vs. $100 \text{ K}_2\text{O}/(\text{K}_2\text{O} + \text{Na}_2\text{O})$, Wasekwan Group, showing the "spectrum" of igneous compositions (Hughes, 1972). Samples which plot inside the "igneous spectrum" are not necessarily unaltered (see text for discussion).

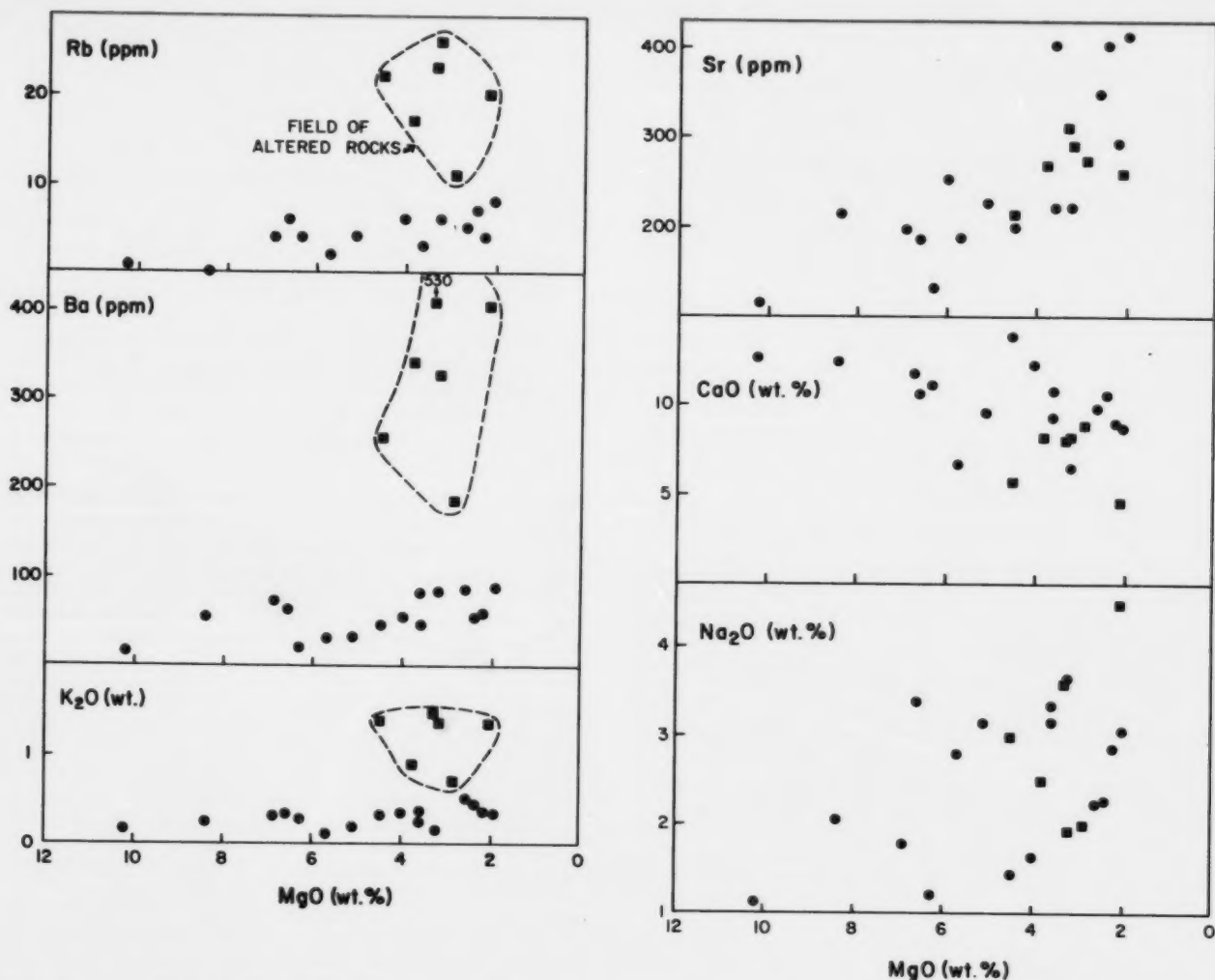


Figure 8: (a) Rb, Ba and K_2O vs. MgO, Northern Belt basalt and andesite. K-metasomatized rocks with elevated Rb, Ba and K_2O can be clearly distinguished from rocks which have not suffered this type of alteration. (b) Sr, CaO and Na_2O vs. MgO. K-metasomatized rocks cannot be distinguished on these plots.

alteration. Both diagrams show that there are Na-metasomatized and K-metasomatized rocks, with a continuum of compositions between the extremes. Although Na-metasomatism predominates in the Wasekwan Group, K-metasomatized rocks include members of the McVeigh Lake and Fox Lake porphyritic basalt, Snake Lake dacite, some rhyolites, and several mafic rocks in the Northern Belt. Potassium is enriched in basalts during low temperature sea-floor alteration so this particular style of alteration might predate the widespread alkali and Ca mobility associated with regional metamorphism.

The effects of K-metasomatism are demonstrated particularly well in the Northern Belt. K_2O , Rb and Ba are clearly elevated above "normal" levels in six out of 22 analyses of basalts and andesites (Fig. 8a). The remainder of the analyses form regular, linear trends on these plots. The anomalous samples come from flows that are an integral part of the sequence which defines the regular trend, so it is probable that these particular rocks have preferentially suffered major alteration affecting concentrations of K_2O , Rb, and Ba. Notably, these rocks are the only ones in the suite which contain significant amounts of metamorphic biotite. These altered rocks cannot be distinguished by their contents

of Sr, CaO and Na_2O (Fig. 8b) although the dispersion of CaO and Na_2O with respect to MgO indicates these elements also have been redistributed in a non-systematic manner. The concentration of Sr shows a general increase with decreasing MgO suggesting that a primary trend is preserved. Figures 8a and 8b illustrate the limited usefulness of K, Na, Rb, Ba and Ca in petrogenetic interpretation of altered rocks, the need for screening data in order to exclude obviously altered specimens, and the usefulness of Ba concentration as an indicator for K-metasomatism.

Epidosite domains are perhaps the most obvious manifestation of element mobility. More localized alteration, possibly of the high temperature hydrothermal type, includes silicification (e.g. rhyolites with more than 78 per cent SiO_2), Mg enrichment (e.g. anthophyllite-bearing schists in the Fox Mine area), and local Na depletion (e.g. basalts with less than 1 per cent Na_2O). Banded and patchy diopside-rich domains in basalts near Fox Lake also indicate Ca mobility. Banding in highly metamorphosed and strongly foliated rocks locally produced metamorphic layering.

SUMMARY OF ELEMENT MOBILITY

All of the analyzed rocks have a multi-stage alteration history. The following conclusions can be made regarding element mobility and the usefulness of certain elements in determining magma type and petrogenesis:

(1) There is widespread evidence for significant mobility of Na, K and Ca. These elements and derived data (e.g. normative an, ab, or) cannot be used to determine, with confidence, the primary compositional variation in a rock suite, its chemical classification, nor its petrogenesis.

(2) Si was mobile during every stage of alteration but apart from obvious silicification the magnitude of the variation is unknown; in mafic rocks it is probably not large enough to significantly affect the rock classification. The presence of minor quartz-filled amygdales in some specimens (especially basalts) has introduced a small amount (less than 3 per cent) of SiO_2 to some analyses.

(3) Primary $\text{Fe}_2\text{O}_3/\text{FeO}$ ratios in the rocks were readjusted during sea-floor alteration and metamorphism. Total iron (as FeO^*) is commonly used in geochemical plots because the arbitrary method of calculating the "primary" value of Fe_2O_3 (e.g. Irvine and Baragar, 1971) probably does not apply throughout the diverse rock suites present (Jolly, 1975). The net loss or addition of iron during alteration is unknown for

any given analysis, but if it is small the change will not significantly affect interpretation. Rocks that show evidence of widespread iron redistribution (for example those with abundant pyrite) were not analyzed.

(4) Mg is likely to have been mobile during all alteration events and there has been local obvious Mg enrichment. Evidence from this study (discussed in a subsequent section) suggests that the overall mobility of Mg was rather low, so the MgO contents of most rocks can be used in interpreting petrogenesis. Similarly, the data of Gélinas et al. (1982) indicate that FeO^*/MgO ratios for most rocks which do not show conspicuous evidence of alteration will reflect primary values.

(5) Sr, Rb and Ba are considered to be mobile during alteration (e.g. Hart, 1973; Smith and Smith, 1976; Ludden et al., 1982) and evidence from this study (below) confirms widespread redistribution of these elements.

(6) Al, Ti and P are probably relatively immobile; Ti is particularly useful in distinguishing different rock suites. Local redistribution of Ti is, however, strongly suspected in some samples.

(7) Cr is generally immobile and Ni may have had only limited mobility (Condie et al., 1977). These elements have proved useful in distinguishing between different units in the mafic to intermediate compositional range.

(8) Rare earth elements (REE) are sufficiently immobile so that recognition of primary patterns is possible (e.g. Ludden et al., 1982; Sun and Nesbitt, 1978; Weaver et al., 1982).

DISTRIBUTION OF MAJOR ROCK TYPES

A histogram of SiO_2 contents in 163 Wasekwan Group volcanic rocks (Fig. 9) shows the overwhelming preponderance of mafic to intermediate compositions (46.0–58.5 per cent SiO_2) with basalt the most common rock type analyzed. Specimens for analysis were chosen to represent most of the rock types encountered and to document the variability within major units, consequently the frequency distribution shown in Figure 9 approximates the presently exposed volumetric abundance of rock types in the belt. Andesite is much less abundant than basalt, and dacite is the least abundant composition in the belt. Rhyolite might be under-represented in Figure 9 because few analyses were made of the large rhyolite body south of Lynn Lake town. All of the rocks are subalkaline with respect to normative mineralogy and alkali content.

Unique or restricted compositions of separate, relatively small dacite and rhyolite bodies account for the distribution of SiO_2 values in the 61.0–78.5 per cent SiO_2 range. There is little overlap in SiO_2 content (or trace element abundance; see below) between the different felsic bodies.

Broad geographic groupings of geochemically related rock types or series have been briefly discussed in the companion paper (Gilbert et al., 1980), in the General Geology section of this report, and are apparent from inspection of the analyses and Figure 9. They can be summarized as follows:

(1) High-MgO basalts occur in the Tod Lake basalt (outcrop belts C, D' and F, Fig. 10). They also occur locally in Division D of the Northern Belt.

(2) High-alumina basalts (containing greater than 17 per cent Al_2O_3) are characteristic of the Northern Belt, where they are inter-

calated with basalts with "normal" Al_2O_3 contents. A few high-alumina basalts also occur in unit 4 in the Gemmell Lake-Franklin Lake segment of the Southern Belt.

(3) Tholeiitic basalts form extensive units (interpreted as shield volcanoes) in the Southern Belt (e.g. Tod Lake basalt, Cockeram Lake basalt). With the porphyritic basalts (below) these rocks comprise the mafic, basal units of the Southern Belt stratigraphy.

(4) Distinctive porphyritic basalts with "primitive" calc-alkaline affinities occur in separate bodies at Fox Lake and McVeigh Lake. Similarities between some members of these two bodies constitute the basis for correlation in the Southern Belt.

(5) Calc-alkaline rocks occur only in the Cartwright Lake-Hughes Lake area.

DEFINITION OF MAJOR BASALT UNITS

Basalt displays considerable diversity in its chemical composition (Table 2). Major bodies of basalt are each geochemically unique, reinforcing the interpretation made from field and petrographic data that each body represents the effusive products of separate eruptive centres. On a diagram in which one of the least mobile elements (Ti, as TiO_2) is plotted against FeO^*/MgO ratio, each of the major basalt units occupies a specific field with little overlap between fields (Fig. 11). Calc-alkaline suites, although displaying some iron enrichment in successive differentiates, do not display the broad range of FeO^*/MgO that characterizes tholeiites (Miyashiro, 1974). On Figure 11 the Tod Lake

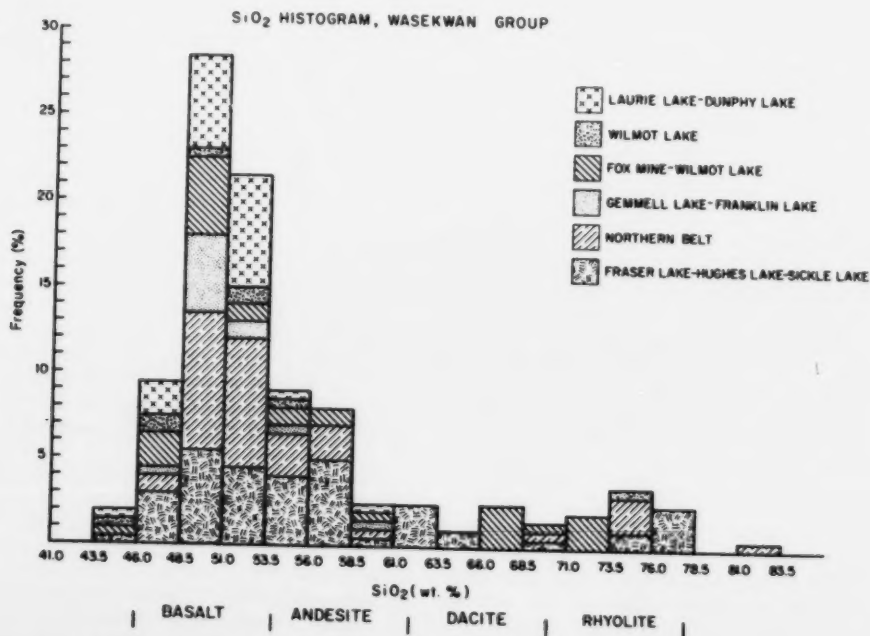


Figure 9: Histogram showing frequency distribution of SiO_2 contents in 163 Wasekwan Group volcanic rocks. Geographic distribution of the various compositions is indicated by patterns on histogram bars.



TiO₂ with increasing FeO*/MgO; trends for the Northern Belt basalts are at constant TiO₂.

13

Table 2:
Average compositions of some major rock types in the Lynn Lake greenstone belt.

Table 2

	1	2	3	4	5	6	7	8	9	10	11	12
SiO ₂	49.92	52.05	52.14	50.93	49.23	52.52	49.82	58.15	58.12	76.13	69.69	77.20
Al ₂ O ₃	14.66	14.38	14.62	9.73	15.00	19.18	19.37	18.48	16.59	12.62	13.91	11.54
Fe ₂ O ₃	2.06	1.65	2.77	0.86	3.39	1.90	2.00	1.37	1.54	0.60	0.81	0.52
FeO	9.82	9.92	8.23	10.07	6.74	7.81	8.22	5.52	5.06	0.83	3.79	1.69
CaO	10.67	9.04	10.04	10.86	10.70	8.93	10.00	8.93	7.30	1.10	2.48	0.96
MgO	7.50	4.82	5.21	11.49	7.34	3.03	4.64	2.35	3.89	0.31	1.23	0.66
Na ₂ O	2.15	3.15	3.16	1.61	2.44	2.92	2.74	2.66	4.11	3.93	3.46	3.17
K ₂ O	0.18	0.54	0.34	0.42	1.43	0.81	0.36	0.46	0.59	2.87	2.74	3.29
TiO ₂	1.11	1.58	1.04	0.84	0.96	0.97	0.78	0.79	0.76	0.15	0.47	0.15
P ₂ O ₅	0.08	0.18	0.15	0.13	0.26	0.22	0.10	0.20	0.24	0.01	0.10	0.04
MnO	0.18	0.21	0.20	0.24	0.19	0.20	0.19	0.14	0.12	0.07	0.09	0.04
H ₂ O	1.52	1.53	1.28	1.69	1.59	1.16	1.48	0.75	1.48	0.67	0.84	0.41
S	0.03	0.04	0.08	0.03	0.01	0	0	0	0.03	0.01	0.03	0
CO ₂	0.17	0.99	0.60	0.72	0.43	0.17	0.24	0.10	0.21	0.59	0.32	0.23
Rb	1		6	15*	23*	9	2	10	9	36	64	71*
Sr	140		211	278*	678	363	209	314	375	68	119	140
Ba	45		183	230*	583*	129	48	169	250	1066	629*	936*
Th			0.7	2.4	3.0	0.8	<0.5	1.0	2.4	8.3	8.2	9.8
U			0.4	0.7	0.9	0.8	0.3	0.7	1.0	3.0	2.2	2.4
Nb	8		5	8	7	6	5	8	8	13	9	14
Hf			1.7	1.4	2.1	0.9						
Zr	80		75	74	112	104	54	117	136	105	152	209
Y	28		30	22	21	23	16	25	25	51	28	38
Ga	22		23	20	25	26	23	24	22	21	21	23
Ni	110*	16	46	123	53	<5	13	3	59	4	4	4
Cr	259*	47	79	1267*	276	<15	36	17	64	4	9	<10
V	354*		310	268	235	186	214	136	152	3	43	10
Cu	197		103	56	106	67	106	49	62	6	13	15
Pb	2		5	5	5	5	3	4	2	10*	4	7
Zn	102		114	98	91	95	83	92	76	50	72	122
Rb/Sr	0.01		0.03			0.02	0.01	0.03	0.02	0.53	0.54	0.51
Ti/Zr	83		83	68	51	56	87	40	34	8.6	18.5	4.3
Ti/Y	238		208	229	274	253	292	189	182	17.6	101	23.6
Zr/Y	2.9		2.5	3.4	5.3	4.5	3.4	4.7	5.4	2.1	5.4	5.5

*Significant variation between samples.

- 1 Tod Lake basalt, outcrop belts C and D; analyses 156-158, 162-164
- 2 Tod Lake basalt, outcrop belts B' and B''; analyses 150-155
- 3 Cockerm Lake tholeiitic basalt; analyses 1-7
- 4 Fox Lake porphyritic, "primitive" calc-alkaline basalt; analyses 114-122
- 5 McVeigh Lake porphyritic, "primitive" calc-alkaline basalt; analyses 14-17
- 6 Northern Belt Division B high-alumina basalt; analyses 63-65, 67, 69, 70
- 7 Northern Belt Division D high-alumina basalt; analyses 79-81, 86, 88, 90
- 8 Northern Belt Division B high-alumina andesite; analyses 72-74
- 9 Hughes Lake calc-alkaline andesite; analyses 30-36, 38
- 10 Calc-alkaline rhyolites, Hughes Lake area; analyses 42-47. Trace elements from the Cartwright Lake body only.
- 11 Snake Lake dacite/rhyolite; analyses 131-139
- 12 Lynn Lake rhyolite; analyses 76-78

THOLEIITIC BASALTS

TOD LAKE BASALT

The Tod Lake basalt is stratigraphically significant because it straddles the boundary between the Lynn Lake greenstone belt and the Kiseynew sedimentary gneiss belt. It is interpreted as part of a platform or shield volcano, with predominant flows in the thick proximal section (near Fox Mine), passing laterally into progressively more fragmental lithologies (breccia, tuff) in the thinner distal section, within the gneissic belt.

Successive outcrop belts B to G (Fig. 10) are interpreted to represent increasingly more basinward facies of the one or more basaltic units comprising the Tod Lake basalt. The proximal parts of the unit (in belts B' and C) are in fault contact with various other volcanic units and the age of the Tod Lake basalt relative to the rest of the Wasekwan Group is unknown. In outcrop belts C through G the basalt conformably overlies Burntwood River Metamorphic Suite metagreywacke-mudstone and is apparently overlain conformably by Sickle Group arkose and conglomerate.

The Tod Lake basalt comprises a suite of rocks with a wide compositional range, from high-magnesia basalt (MgO up to 17.1 per cent) to basaltic andesite (55.95 per cent SiO₂, 3.73 per cent MgO). The most magnesian varieties occur in the distal facies, near the top of the basaltic succession, and the least magnesian types are restricted to the thickest part of the pile south of Hatchet Lake.

On a plot of TiO₂ vs. FeO*/MgO (Fig. 12) analyses from outcrop belts B' to D' lie on a trend line of increasing TiO₂ with increasing FeO*/MgO; analyses from outcrop belts B' + B'' and C + D' do overlap. The wide range of FeO*/MgO indicates that this portion of the Tod Lake basalt has tholeiitic affinities; the average composition of outcrop belt B' + B'' is similar to the average Cockeram Lake basalt (Table 2) but with somewhat lower Ni and Cr. They are the most Fe- and Ti-rich members of the Tod Lake basalt. Outcrop belts C + D contain both iron-rich basalts and basalts with high MgO (up to 11.5 per cent) and FeO* (up to 15 per cent) with normal to high TiO₂ contents. The rare earth element (REE) pattern of a pillowed basalt from outcrop belt D (sample 158) is flat and unfractionated, with La_N/Yb_N = 1.1 and Yb_N approximately 10 times chondrite (Fig. 13).

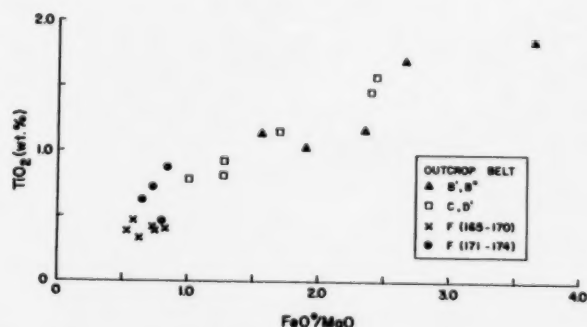


Figure 12: TiO₂ vs. FeO*/MgO, Tod Lake basalt.

Outcrop belt F contains most of the high-MgO (greater than 10 per cent MgO) members of the Tod Lake basalt. The high-MgO suite forms the uppermost unit of the Burntwood River Metamorphic Suite on the north margin of the Kiseynew belt. Analyses 165 through 170 represent a 50 m thick stratigraphic section through outcrop belt F; they show a clear trend to higher MgO and lower FeO*/MgO from base to top of the unit. The most magnesian analysis (17.1 per cent MgO), at the top of the unit, is close to an ultramafic composition. The high-MgO suite comprises mainly layered tuff and local breccia, but primary structures are generally not well preserved and textures are wholly metamorphic. Alteration of these originally fine grained lithologies probably produced significant element redistribution and the analyses are unlikely to represent melt compositions; nevertheless, the high-MgO suite forms a distinctive stratigraphic entity that can be identified within the Kiseynew belt as far south as Russell Lake, 60 km south of Fox Mine (Lenton, 1976) and as far southeast as Granville Lake (Zwanig, 1981).

The analyses from outcrop belt F, and especially those from the 50 m thick section of the unit on northeast Laurie Lake, are distinguished by exceptionally low TiO₂ (Fig. 12). A continuum of TiO₂ contents exists between the various members of the suite (Figs. 12, 14). On Figure 15, analyses from outcrop belt F are characterized by low and constant FeO*/(FeO* + MgO) ratios; there is a continuum of FeO*/(FeO* + MgO) for the entire suite. A general trend to lower TiO₂, FeO*/(FeO* + MgO) and higher MgO is present from outcrop belts B to F.

La_N/Yb_N is a ratio in which the measured concentrations of La and Yb in the sample are normalized to (divided by) the abundance of La and Yb, respectively, in a standard chondritic meteorite (Table A3, Appendix). This ratio reflects the slope of the REE pattern, i.e. the abundance of the light REE (LREE = La, Ce, Pr, Nd) relative to the heavy REE (HREE = Dy, Ho, Er, Tm, Yb, Lu). "Fractionated" patterns are those in which there is significant enrichment of LREE relative to HREE, or significant enrichment of all REE over chondritic abundances.

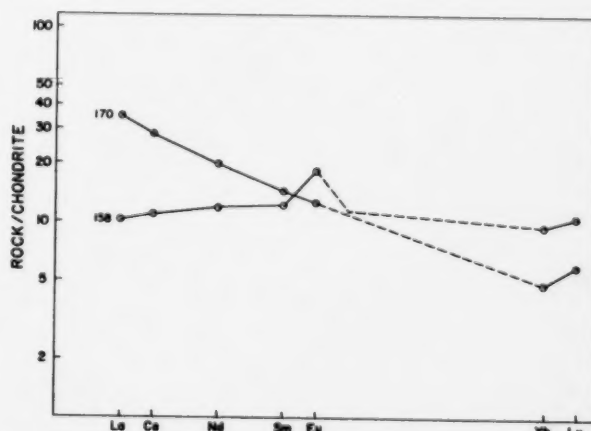


Figure 13: Chondrite normalized plot of rare earth element (REE) abundances in two different members of the Tod Lake basalt. Patterns are identified by analysis numbers corresponding to those in the Appendix.

The REE pattern of sample 170, with 17.1 weight per cent MgO, is strongly fractionated ($La_N/Yb_N = 7.3$; Fig. 13). Archean komatiites are characterized by LREE-depleted patterns with La_N/Yb_N less than 1 (e.g. Sun and Nesbitt, 1978), thus it is highly unlikely that the magnesian rocks in outcrop belt F are komatiitic. In fact, these rocks are similar to the "primitive" calc-alkaline suite.

The high-MgO suite is significant in that it coincides with the transition between the Lynn Lake volcanic/volcanogenic terrane and the Kiseynew metasedimentary belt. Possibly the (extensional?) tectonic regime in that critical area allowed tapping of upper mantle partial melts and eruption of high-MgO magmas. The trend to higher MgO upward through the stratigraphic section in outcrop belt F suggests progressive emptying of a compositionally zoned magma chamber. If so, none of the rocks represent unmodified primitive compositions but are various members of a differentiation suite. On Figure 16, Tod Lake basalt analyses from outcrop belt F are dispersed about a pyroxene control line, suggesting that precipitation of sub-calcic pyroxene could have produced the observed compositional variation.

Differentiated mafic and ultramafic sills in outcrop belt D (analyses 175-181) are similar in bulk composition and TiO_2 content to the high-MgO members of the Tod Lake basalt (Fig. 11). Note that analyses from the 5 m thick ultramafic body lie on an olivine control line on Figure 16, indicating that precipitation of olivine is responsible for the compositional variation through the sill.

COCKERAM LAKE BASALT

The Cockeram Lake aphyric basalt pile is interpreted as an isoclinally folded shield volcano whose present dimensions are 26 km by at least 2100 m. It is the oldest rock unit in the east-central part of the Southern Belt. The basalt is intercalated in the west with McVeigh Lake porphyritic basalt and is overlain at Cartwright Lake by calc-alkaline andesites of the Hughes Lake suite (Table 1).

Cockeram Lake basalt is subalkaline with significant hypersthene (0.97–20.94 per cent) and quartz (0.95–7.57 per cent) in the norm. It displays a range of FeO^*/MgO ratios (Fig. 11) and plots in the tholeiitic field on a Jensen cation plot (Fig. 17); accordingly it is best termed a quartz tholeiite. In detail the geochemical characteristics of the Cockeram Lake basalt include the following:

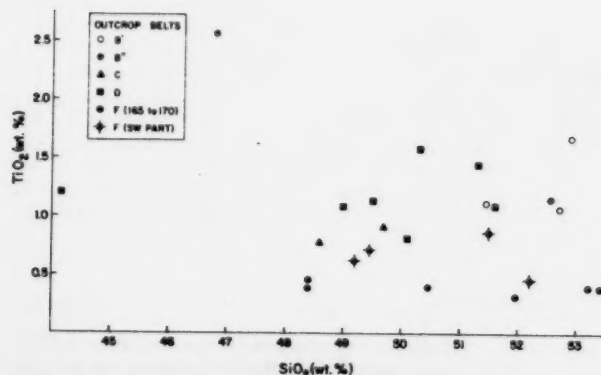


Figure 14: TiO_2 vs. SiO_2 , Tod Lake basalt.

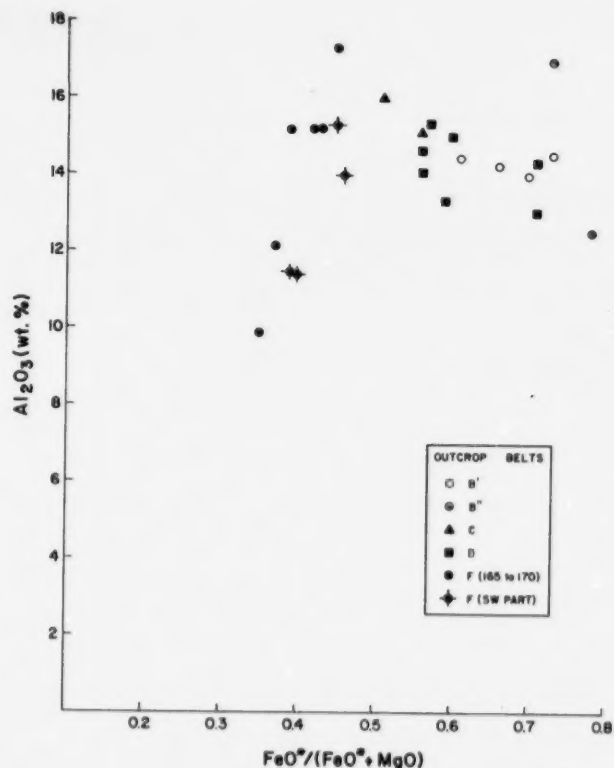


Figure 15: Al_2O_3 vs. $FeO^*/(FeO^* + MgO)$, Tod Lake basalt.

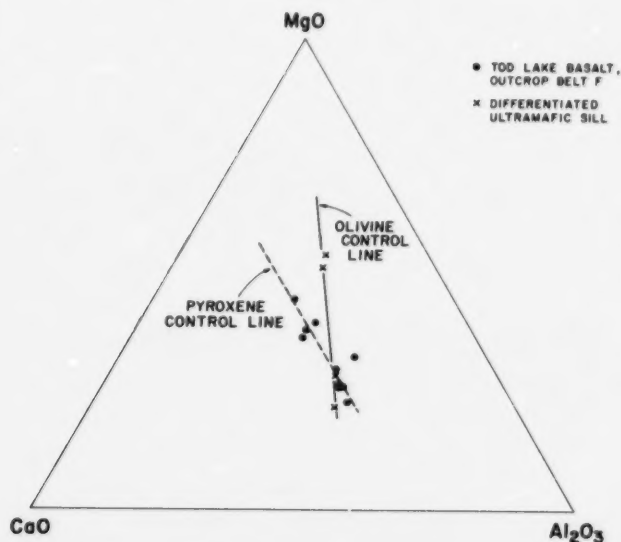


Figure 16: CaO - MgO - Al_2O_3 plot of rocks from Tod Lake basalt. Oxides in weight per cent.

(1) Mg-numbers¹ range from 36 to 61 and average 50. Mg-numbers of least refractory upper mantle peridotite compositions are approximately 88-89 and basaltic magmas derived from such a source peridotite must have Mg-numbers of approximately 68-75 for up to 30 per cent partial melting (Frey et al., 1978). Consequently the Cockeram Lake basalts cannot represent "primitive" unfractionated magmas derived unmodified from a mantle source, but must have undergone crystal fractionation at some unspecified depth prior to eruption.

(2) Average contents of Ni and Cr (Table 2) are low compared to mid-ocean ridge basalts (MORB, e.g. Table A5, Appendix) and Archean tholeiites (Table A4, Appendix), but are similar to Ni and Cr contents in "typical" island arc tholeiites (Table A5, Appendix).

(3) TiO_2 concentrations are low to moderate (0.59–1.44 per cent), generally somewhat lower than Archean tholeiites (Table A4, Appendix).

(4) Ti/Zr ratios range from 71 to 103 and average 86. This value is low compared to a typical value of 110 in chondrites, MORB, Archean tholeiites and spinifex-textured peridotites (Sun et al., 1979) and "primitive" island arc tholeiites (e.g. Table A7, Appendix).

(5) Rare earth element patterns (Fig. 18) are mildly fractionated, with HREE abundance about 19 times chondritic values, weak LREE enrichment ($\text{La}_N/\text{Sm}_N = 1.6\text{--}1.8$) and no Eu anomaly. By contrast, normal-type MORB has lower HREE abundances (8-15 times chondritic values) and LREE depletion ($\text{La}_N/\text{Sm}_N = 0.4\text{--}0.7$; e.g. Sun et al., 1979; Kay and Hubbard, 1978). Island arc tholeiites commonly display flat, mildly fractionated, or LREE-depleted patterns with HREE abundances about 4-20 times chondritic values (e.g. Arth, 1981; Hawkesworth et al., 1977).

The low Mg-numbers, relatively high REE abundance and low Ti/Zr ratio in the Cockeram Lake basalt suggest that it has experienced some crystal fractionation, probably involving pyroxene (Sun et al., 1979). Low contents of Ni and Cr are consistent with olivine and pyroxene fractionation. The absence of an Eu anomaly indicates that plagioclase was not a fractionating phase. Fractionation probably occurred in a high level subvolcanic magma chamber, as in modern island arcs (Meijer and Reagan, 1981; Stern, 1979).

¹Mg-numbers are $100 \text{ Mg}/(\text{Mg} + \text{Fe}^{2+})$, with Fe apportioned such that $\text{Fe}_2\text{O}_3 = 0.15 \text{ FeO}^*$.

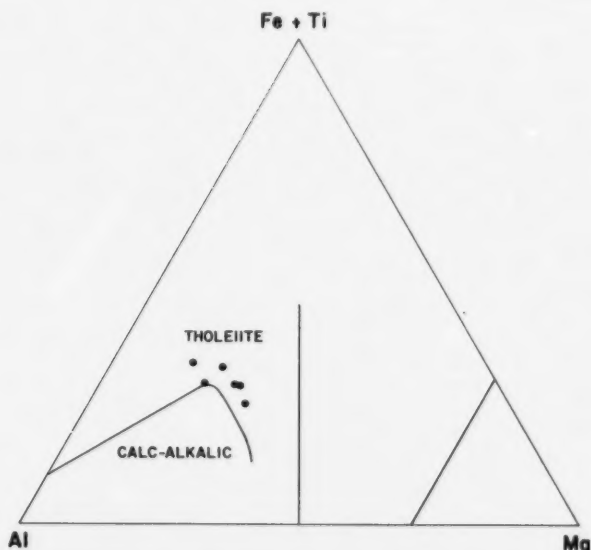


Figure 17: Jensen cation plot, Cockeram Lake basalt.

The major and trace element composition of the Cockeram Lake basalt is clearly different than the compositions of basalts which are being erupted at modern ocean ridges. Evidence presented here and in a subsequent section shows that this basalt is compositionally similar to somewhat fractionated island arc tholeiite.

NORTHERN BELT BASALTS

The Northern Belt is a homoclinal north-facing sequence of basaltic flows, breccia and tuff, with subordinate andesite, rhyolite and volcanogenic sediments. It is physically separated from the Southern Belt by a chain of tonalite plutons, and joins the Southern Belt only in a poorly exposed "T"-shaped junction north of Hughes Lake. Northern Belt type lithologies continue eastward into the Barrington-Magrath-Fraser Lakes area (Gilbert, 1979, 1980). The basalts in the Lynn Lake-Arbour Lake portion of the Northern Belt can be divided stratigraphically and geochemically into an older, more fractionated and evolved Division (B) and a younger, less fractionated, more magnesian Division (D). The two basaltic Divisions are separated by a discontinuous sedimentary Division (C). Division B is underlain for much of its strike length by the Lynn Lake rhyolite complex (Baldwin, 1983); Division D is overlain by Division E basaltic tuff, flows, breccia and greywacke. High-alumina plagioclase-phyric basalts are intercalated with more magnesian and less aluminous basalts in each of Divisions B and D. The low Ni, Cr, Mg and Ti contents of the suite, and the weak trends of iron enrichment within each Division, are similar to the chemical characteristics of island arc tholeiites (c.f. Jakes and Gill, 1970). The following paragraphs, and Tables 2 and A1, outline in more detail the geochemistry of the suite.

A compositional gap exists between Northern Belt basalts with high- Al_2O_3 /low-MgO contents and basalts with lower Al_2O_3 /higher MgO contents (Fig. 19), thereby dividing the entire suite into high-alumina and "normal"-alumina members. There is a slight positive correlation between Al_2O_3 content and plagioclase phenocryst abundance in high-alumina basalt. The high-alumina nature of the majority of flows in the Northern Belt distinguishes it from the Southern Belt which, with the exceptions noted below, contains no high-alumina rocks.

Northern Belt basalts in both Divisions B and D display mild Fe enrichment (Fig. 20) when "normal" and high-alumina types are considered together; individually, however, the high-alumina rocks show trends of steadily decreasing FeO^* with decreasing MgO. On a Jensen plot (Fig. 21) the entire compositional range from basalt through andesite

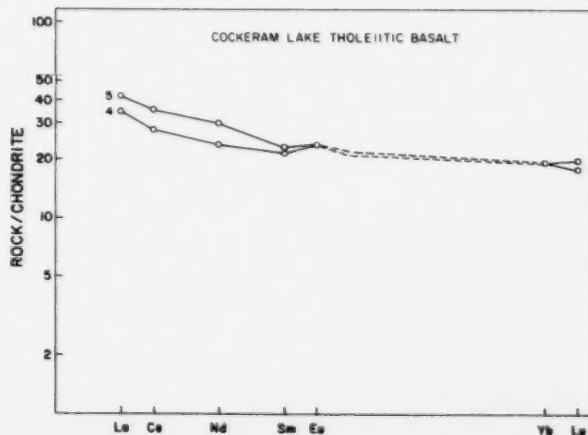


Figure 18: Chondrite normalized REE plot, Cockeram Lake basalt.

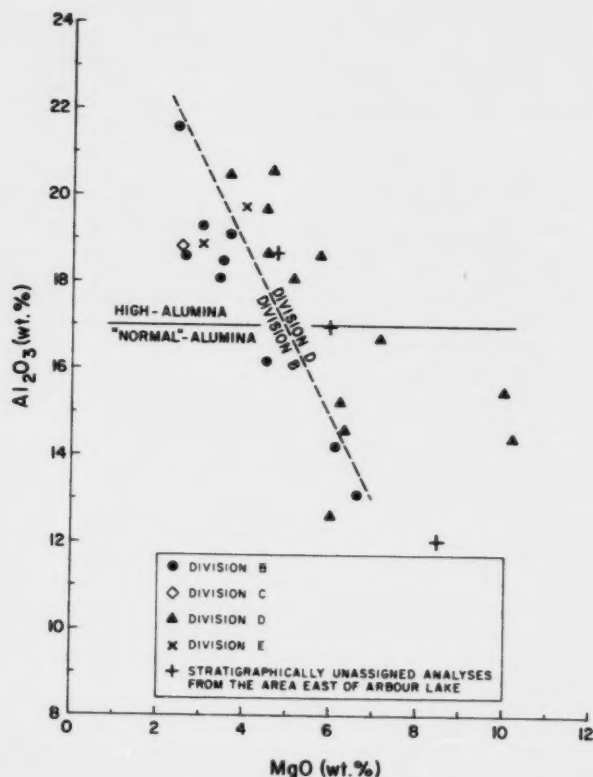


Figure 19: Al_2O_3 vs. MgO , Northern Belt basalts.

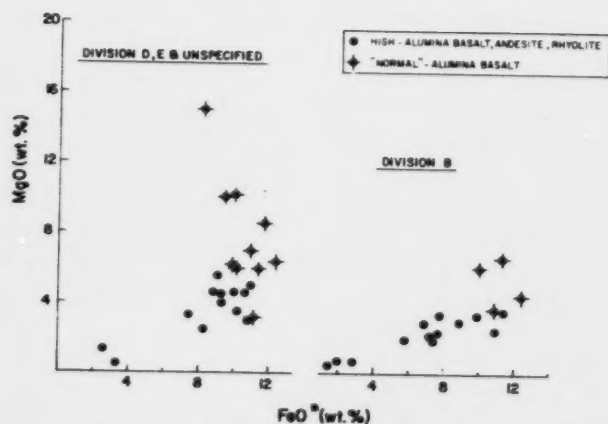


Figure 20: MgO vs. FeO^* , Northern Belt basalts.

in Division B clearly falls in the tholeiite field; Division D high-alumina basalts fall in the calc-alkaline field despite their being part of an overall mild Fe enrichment trend. In strict terms therefore the Northern Belt basalts have both tholeiitic and calc-alkaline affinities. A similar ambiguity exists in some Cenozoic island arcs, where "calc-alkaline" suites with a relatively low degree of Fe enrichment are described (Dixon and Batiza, 1979; Stern, 1979). The Northern Belt suite is clearly different in rock types and chemistry from an unambiguously calc-alkaline suite at Hughes Lake; consequently in this report the Northern Belt rocks are considered to be tholeiites.

Division D basalts are characterized by higher MgO contents and higher Mg -numbers than Division B basalts, at equivalent Al_2O_3 (Fig. 19); this relationship holds for both the high-alumina basalts and the associated basalts with lower Al_2O_3 contents. Division D high-alumina basalts also contain less SiO_2 , incompatible large ion lithophile (LIL) elements (K, Sr, Rb, Ba, Th, U) and high field strength (HFS) elements (P, Ti, Nb, Hf, Zr and Y) than Division B high-alumina basalts; they contain more of the compatible transition metals (Ni, Cr, V) (Table A1, Appendix; Table 2; Fig. 22). Many of these same characteristics also serve to distinguish between Division D and B rocks with "normal" alumina contents: in Division D these basalts contain less Sr, Rb, Ba, P_2O_5 , TiO_2 , Zr and Y, and more MgO and Cr (Table A1, Appendix; Fig. 22). Thus all of the stratigraphically higher Division D rocks appear chemically less fractionated than the earlier Division B rocks, which contain higher incompatible trace element abundances. Division D also contains all high- MgO (greater than 10 per cent MgO) basalts in the Northern Belt, including the "tholeiitic picrites" in the Agassiz Mine area (Fox and Johnston, 1980). The contact between Divisions B and D, where sedimentary rocks of Division C are not present, is not identifiable in the field. Analyzed rocks from the zone where the contact is interpreted to occur are transitional, in their trace and major element chemistry, between typical Division B and D characteristics. There are insufficient data, however, to conclude whether the contact is abrupt or gradational.

Stratigraphically unassigned analyses from the northeast portion of the Northern Belt are chemically similar to Division D (Fig. 19). The only occurrences of high-alumina basalts in the Southern Belt (in the Gemmell Lake-Franklin Lake area) are chemically similar to basalts in both Divisions B and D. The associated lower- Al_2O_3 basalts are similar to "normal" $-Al_2O_3$ basalts in Division D.

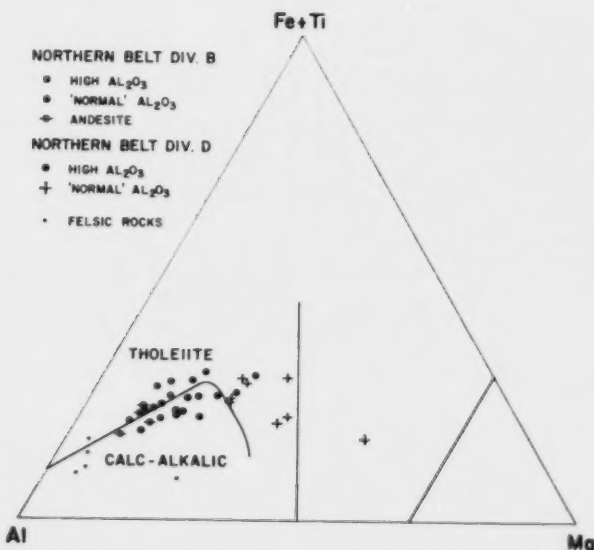


Figure 21: Jensen cation plot, Northern Belt Divisions B and D.

The high-alumina basalts of the Northern Belt are distinguished from all other basalt units in the Lynn Lake region by their very low transition metal contents: Ni (0-30 ppm), Cr (7-90 ppm) and, to a lesser extent, V (160-254 ppm). In this respect they closely resemble the high-alumina basalts of island arcs (10-45 ppm Ni, 10-95 ppm Cr, 270-313 ppm V; Meijer and Reagan, 1981; Dixon and Batiza, 1979; Gorton, 1977; Gunn, 1976), rather than high-alumina basalts of oceanic ridges (60-100 ppm Ni; Gunn, 1976). The contents of Rb, Sr and Ba in Northern Belt high-alumina basalts are also similar to contents of these elements in island arc tholeiites (cf. Jakes and Gill, 1970), although admittedly Rb, Sr and Ba are all mobile during alteration.

Rare earth element abundances further serve to distinguish high-alumina basalts from "normal"-alumina basalts and Division B rocks from Division D rocks (Figs. 23a and 23b). High-alumina basalts are characterized by weak to moderate LREE enrichment ($La_N/Yb_N = 1.7$ to 4.6), relatively low HREE abundances (about 5-10 times chondrite) and positive Eu anomalies which decrease progressively from Eu/Eu^*

$= 1.6$ to 1.0 with increase in absolute REE abundance. "Normal"-alumina basalts show generally flat REE patterns ($La_N/Yb_N = 0.9$ to 1.5, one value at 3.3), higher HREE abundances (about 10-15 times chondrite) and very weak to moderate positive Eu anomalies ($Eu/Eu^* = 1.1$ to 1.5). In both high-alumina and "normal"-alumina suites, Division D has lower total REE concentrations than Division B. Associated high-alumina andesites in Division B have fractionated REE patterns (Fig. 24) virtually identical to the most fractionated high-alumina basalts: $La_N/Yb_N = 3.1$ to 4.3, HREE concentrations are about 10 times chondrite, and there are no Eu anomalies.

The Lynn Lake rhyolite complex, a large (18 km by up to 3 km) composite felsic body composed of flows, pyroclastic rocks, and minor interlayered amphibolite (Baldwin, 1983) forms the lowermost stratigraphic Division (A) in the Northern Belt. It is underlain by a polymictic conglomerate containing volcanic and plutonic clasts (Baldwin, op. cit.). The REE chemistry of this body is briefly considered here because the rhyolite is an integral part of the Northern Belt. The rhyolite displays a fractionated REE pattern characterized by LREE enrichment ($La_N/Sm_N = 2.4$ to 2.9), flat HREE (about 15-25 times chondrite) and negative Eu anomalies in two of the three samples.

The most common explanation of an Eu anomaly is that it is caused by plagioclase involvement, because the plagioclase structure preferentially incorporates Eu^{2+} , thereby extracting Eu relative to the other, trivalent, REE. If plagioclase is removed (by crystal settling) from a liquid, that liquid develops a negative Eu anomaly; if plagioclase is added, the crystal-enriched liquid develops a positive Eu anomaly. Similarly, plagioclase remaining in the solid residue during partial melting will produce a negative Eu anomaly in the melt phase.

REE patterns of some of the high-alumina rocks in the Northern Belt clearly indicate they have incorporated plagioclase crystals: note the well defined positive Eu anomalies, particularly in Division D. Division D samples 80 and 86 also show a positive correlation between the magnitude of the Eu anomaly and the modal abundance of plagioclase phenocrysts. Division B high-alumina rocks display small to negligible positive Eu anomalies, despite a significant modal abundance of plagioclase phenocrysts. These rocks, both basalts and andesites, apparently owe their high-alumina character not to introduction of plagioclase but to a primary aluminous magma composition.

Eu/Eu^* is the measured concentration of Eu in the sample divided by an interpolated value (Eu^*) derived assuming a smooth curve between Sm and Gd.

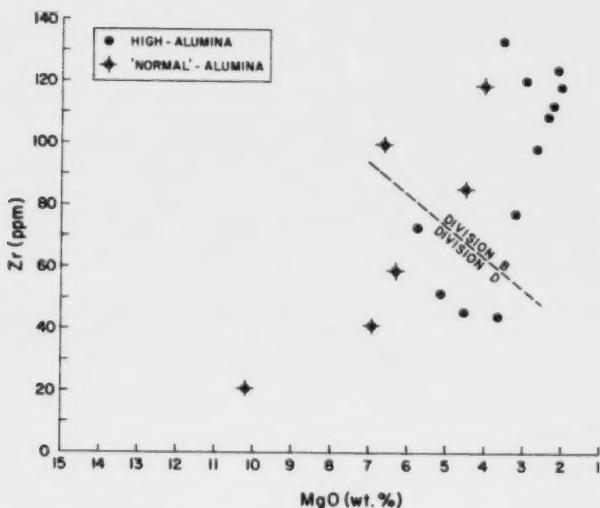


Figure 22: Zr vs. MgO, Northern Belt basalt, andesite.

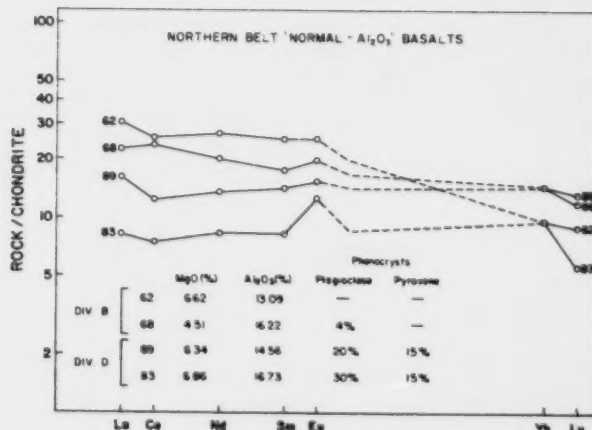
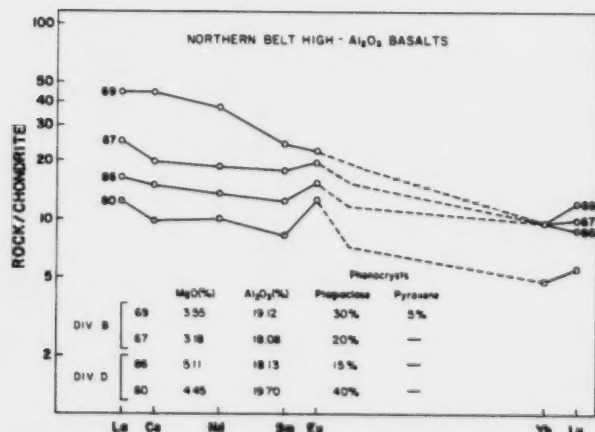


Figure 23: Chondrite normalized REE plots, Northern Belt. (a) high- Al_2O_3 basalts (b) "normal"- Al_2O_3

In rocks with a "normal"-alumina content, sample 83, with 30 per cent plagioclase phenocrysts, displays a significant positive Eu anomaly and probably represents a lava which has accumulated plagioclase crystals. The other samples show negligible Eu anomalies and 0 to 20 per cent plagioclase phenocrysts; the phenocrysts in these lavas are apparently cognate.

MODEL OF NORTHERN BELT PETROGENESIS

The REE, major and trace element data of the Northern Belt can be integrated into a model which reconciles many of its major stratigraphic and geochemical features. The major features which must be considered are:

- (1) The "inverted" compositional sequence, beginning with rhyolite (Division A), overlain by fractionated high-alumina basalts and andesites intercalated with "normal"-alumina basalts (Division B), overlain by sediments (Division C), overlain by less-fractionated high-alumina basalts, "normal"-alumina basalts, and high-MgO basalts (Division D).
- (2) Lower Mg-numbers, higher incompatible trace element abundances and lower compatible transition metal abundances in Division B relative to Division D.
- (3) Evidence for plagioclase-enrichment in some high-alumina basalts.
- (4) Low Ni, Cr, TiO₂ and V concentrations in the entire mafic suite.
- (5) Negative Eu anomalies in the Lynn Lake rhyolite, indicating that these rocks were probably derived by crystal fractionation which involved separation of plagioclase.

As a simplistic model of Northern Belt petrogenesis it is proposed that crystal fractionation of a parental aluminous basalt magma occurred in a large high-level magma chamber (Fig. 25). An unmodified representative of the primitive aluminous magma has not been identified in the stratigraphy of the Northern Belt: all analysed rocks appear to be from derived liquids containing varying amounts (0 to 50 per cent) of cumulus crystals. The alumina content of the primitive magma is estimated to have been about 17 per cent.

Early crystal fractionation of olivine, pyroxene and Fe-Ti oxides from the primitive aluminous magma would produce a fractionated aluminous basalt liquid depleted in MgO, Ni, Cr, V, TiO₂ and, to a lesser extent, Fe³⁺. Incompatible minor and trace element abundances

and bulk REE abundances would become elevated relative to those in the primitive magma. The middle and heavy REE are retained somewhat by pyroxene relative to the light REE (Hanson, 1978), so removal of pyroxene would result in mildly LREE-enriched liquids. The alumina content would be slightly higher than in the primitive magma because aluminous phases were not separating at this early stage. The early precipitation of Fe-Ti oxides would have precluded trends to greater Fe enrichment during subsequent differentiation.

As olivine ceased to be a fractionating phase and plagioclase appeared on the liquidus, joining pyroxene and Fe-Ti oxides, continued fractionation would further deplete the magma in MgO, TiO₂ and Fe³⁺. Al₂O₃, CaO, Sr and Eu²⁺ would begin to be removed in the plagioclase whereas incompatible minor and trace elements would remain in the magma. Nickel (and Cr?) would remain approximately constant, having been strongly depleted by the early precipitation of olivine and Cr-bearing pyroxene. Bulk REE abundances would continue to increase, with increase in La/Yb ratio; the most felsic derived liquids would be depleted in Eu relative to other REE. Ultimately a compositionally zoned magma chamber would be established (e.g. Smith, 1979) with rhyolite at the top, succeeded downward by a small volume of andesite and fractionated basalt, and a large volume of less fractionated, crystal-rich basalt (Fig. 25). Convective mixing would be confined to the mafic portion of the magma chamber (Hildreth, 1979).

Progressive emptying of such a zoned magma chamber would reproduce, in inverted order, the compositional zonation in the chamber. Baldwin (pers. comm., 1984) has suggested that the Lynn Lake rhyolite complex, which is dominated by pyroclastic rocks, was deposited in a caldera. In this model, the progressive eruption of the contents of the Northern Belt magma chamber would have been initiated by caldera collapse and deposition of the Lynn Lake rhyolite, with its fractionated REE pattern and negative Eu anomalies. Division B high-alumina andesite with fractionated REE patterns and high dispersed trace element contents (Table 2) was erupted following emplacement of the Lynn Lake rhyolite. The absence of Eu anomalies in these rocks may be due to separation of approximately equal proportions of plagioclase and clinopyroxene (Hanson, 1978). Division B high-alumina basalt with fractionated REE patterns was erupted penecontemporaneously with the andesites; "normal"-alumina basalts in Division B may represent liquids derived from somewhat deeper in the magma chamber, enriched in cumulus pyroxene.

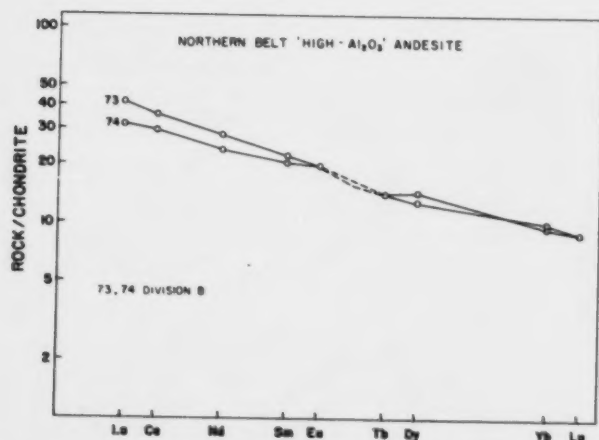


Figure 24: Chondrite normalized REE plots, Northern Belt high-Al₂O₃ andesites.

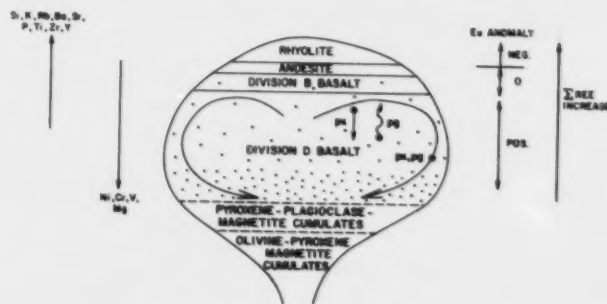


Figure 25: Model of Northern Belt high level zoned magma chamber showing compositional gradients deduced from erupted products. See text for discussion.

The sedimentary Division (C) which separates Divisions B and D throughout much of the Northern Belt indicates a local pause or decrease in volcanic activity, a pause that was followed by renewed eruption of high-alumina, "normal"-alumina and subordinate high-MgO basalts. These basalts commonly have positive Eu anomalies, indicating that they represent magmas which were enriched in cumulus plagioclase: note that they contain up to 50 per cent modal plagioclase and pyroxene phenocrysts (Table A1, Appendix; Fig. 23). In this model they are considered to have been erupted from the crystal-enriched, convectively mixed lower half of the zoned magma chamber. Division D high-alumina basalts may have been tapped from plagioclase-rich upper portions of the magma chamber, whereas "normal"-alumina basalts may represent liquids derived from deeper in the chamber, enriched in both pyroxene and plagioclase. High-MgO basalts in the Northern Belt are poorly known in both chemistry and areal distribution; they appear to increase in abundance towards the top of Division D. They may represent liquids derived from the lower part of the magma chamber, considerably enriched in pyroxene (and locally olivine?). The main high-MgO unit in the Northern Belt occurs in the footwall of the Agassiz Au deposit, where it is overlain by iron formation and hydrothermally altered, Au-bearing rocks. This unit may represent another period of volcanic quiescence, accompanied by hydrothermal activity and Au concentration.

HUGHES LAKE BASALT

The Hughes Lake basalt represents a small segment of a 1 km thick, subaqueous basaltic pile which overlies the Hughes Lake calc-alkaline sequence and is overlain by 200 m of conglomerate, greywacke and siltstone. This basalt lacks normative nepheline, and contains 6.22 to 17.79 per cent normative hypersthene and 6.26 to 8.26 per cent normative olivine; it displays a weak trend to increasing $\text{FeO}^*/(\text{FeO}^* + \text{MgO})$ with increasing stratigraphic elevation (Fig. 26). Mg-numbers range from 48 to 58. In these respects the basalt resembles an olivine tholeiite. The concentration of P_2O_5 is high (0.23-0.68, average 0.39 weight per cent), relative to other tholeiitic suites, but TiO_2 contents are moderate (0.87-1.78 weight per cent) and within the general range of Southern Belt aphyric basalts. Abundances of Ni (66-128 ppm) and Cr (80-270 ppm) are comparable to but slightly greater than the Cockeram Lake

quartz tholeiites. Hughes Lake basalt contains less Zn, Cu, Ba and V than Cockeram Lake basalts but has a greater concentration of Zr and higher Zr/Y ratios (Tables A2, Appendix).

The REE patterns of two Hughes Lake basalt samples are remarkable, for olivine-normative rocks, in that they are fractionated, LREE-enriched ($\text{La}_N/\text{Yb}_N = 2.9$ to 5.1), with $\text{La}_N = 41$ to 73 times chondrite (Fig. 27). Both samples have very small positive Eu anomalies ($\text{Eu}/\text{Eu}^* = 1.1$ to 1.2). The REE patterns are obviously very different from "average" MORB (La_N/Yb_N approximately 0.75, e.g. Sun et al., 1979) and island arc and back-arc tholeiites (La_N/Yb_N approximately 0.38 to 3.1; Hawkesworth et al., 1977; Arth, 1981; Sun, 1980). In bulk REE abundance and La/Yb ratio they are similar to the Hughes calc-alkaline basalts and to "least-fractionated" alkalic basalts from island arcs (Arth, 1981).

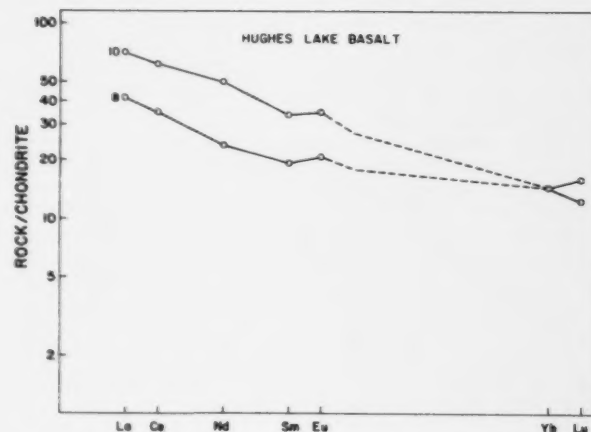


Figure 27: Chondrite normalized REE plots, Hughes Lake transitional basalt.

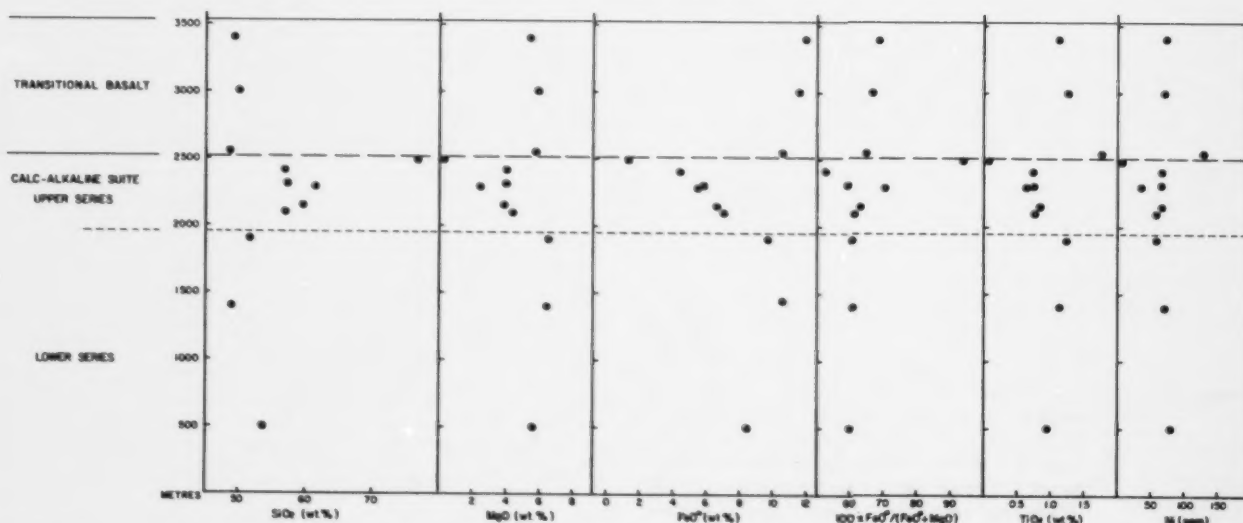


Figure 26: Variation in chemical composition with stratigraphic elevation, in the volcanic section southeast of Hughes Lake. The contact between the calc-alkaline suite and the overlying transitional basalt is chemically abrupt.

The Hughes Lake basalts are unequivocally neither tholeiites nor alkalic basalts: they lack the high contents of alkalis, Rb, Sr and TiO_2 of true alkalic basalts but contain high P_2O_5 , LREE and Zr, features which are atypical of unfractionated tholeiites. In this report these olivine-normative basalts are termed transitional basalts, following Bevier (1983). Hughes Lake transitional basalts do not have the high MgO and TiO_2 of transitional basalts from continental localities (Bevier, 1983, and references therein).

Hughes Lake transitional basalt is significant principally because it overlies the calc-alkaline sequence at Hughes Lake. The entire calc-alkaline suite is interpreted to lie stratigraphically between the Hughes Lake transitional basalt and the older Cockeram Lake quartz tholeiites; abrupt chemical breaks mark the contacts (e.g. Fig. 26).

FOX MINE SUCCESSION

Basaltic flows in the Fox Mine Succession include aphyric and porphyritic varieties interlayered with each other and with mafic to intermediate breccia and minor felsic volcanic rocks. Fox Mine basalts overlie the Fox Lake porphyritic basalt; fine grained sedimentary rocks are intercalated at the top of the succession. They occur in the footwall succession of the orebody.

Major element chemistry of the basalt flows is characterized by high MgO, low TiO_2 and FeO^*/MgO ; one sample (127) contains high Al_2O_3 . Cr is exceptionally low (134-240 ppm). The chemistry is slightly different than that of other basalt bodies in the Lynn Lake belt (Figs. 28, 29 and 30) but it is similar for two groups of samples taken 6 km apart, along strike (Fig. 4). The data suggest that the Fox Mine Succession basalt extends from the south tip of east-Dunphy Lake southwest beyond Fox Mine. The consistent values of major elements, Ni and Cr between porphyritic and aphyric flows indicates a common magma source, a conclusion which is supported by the textural gradation between the varieties. Similar low Cr, low FeO^*/MgO , low TiO_2 basalts could serve as a marker for mineral exploration.

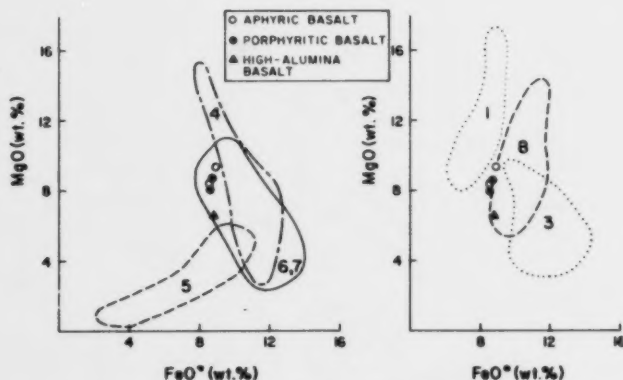


Figure 28:

MgO vs. FeO^* , Fox Mine succession. Compositional fields shown for comparison are 1: Tod Lake basalt, outcrop belt F, 3: Tod Lake basalt, outcrop belts B, C and D, 4: Northern Belt Division D "normal"-alumina basalt, 5: Northern Belt Division D high-alumina basalt, 6: Gemmell Lake-Franklin Lake "normal"-alumina basalt, 7: Gemmell Lake-Franklin Lake high-alumina basalt, and 8: Fox Lake-McVeigh Lake porphyritic basalt.

Fox Mine basalt is in some respects compositionally similar to Division D basalt, Gemmell Lake-Franklin Lake basalt and Fox Lake-McVeigh Lake basalts (Figs. 28 and 29). However, at the appropriate FeO^*/MgO ratios (0.8-1.4), Cr values are too low in Fox Mine basalt (134-240 ppm) for a positive correlation with any of these basalts. Tod Lake basalt is higher in Cr and Ni at the same FeO^*/MgO level.

Some breccias and flows in the succession show chemical evidence of hydrothermal and/or sea-floor alteration. These rocks are pale green weathering, commonly porphyroblastic, with primary pillowed, massive and breccia structures. A porphyritic flow (sample 125) exposed south of Fox Mine contains 60.6 per cent SiO_2 but has Ni and Cr values similar to stratigraphically overlying porphyritic basalt (sample 127); the high SiO_2 is apparently a result of silicification. Large areas of light-coloured rocks with anomalously high Ni, Cr and SiO_2 values reported by Lustig (1979) indicate widespread alteration in the footwall succession at the mine. Low Ni and Cr values (6-14 ppm, 12-47 ppm) of some breccias suggest an intermediate or felsic origin but they too have coarse porphyroblastic textures interpreted to be related to pre-metamorphic chemical alteration.

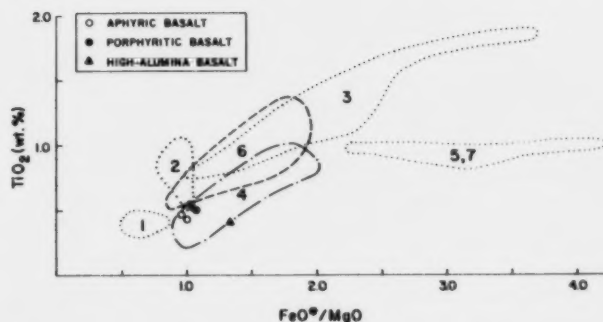


Figure 29:

TiO_2 vs. FeO^*/MgO , Fox Mine succession. Compositional fields shown for comparison are as for Fig. 28, plus 2: Fox Lake porphyritic basalt.

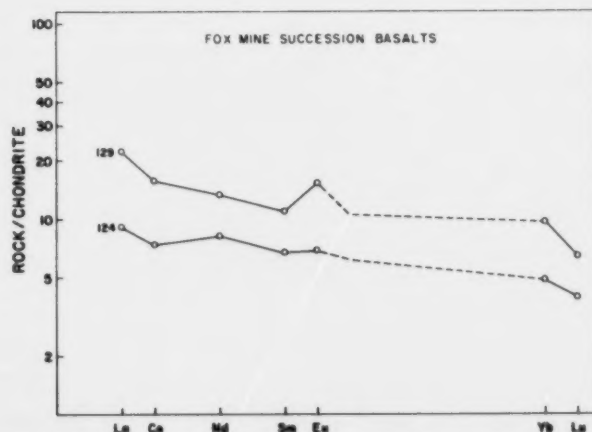


Figure 30:

Chondrite normalized REE plot, Fox Mine succession.

KEEWATIN RIVER BASALTS

Only two analyses of flow rocks are available from the poorly exposed, commonly epidotized mafic rocks from the Keewatin River belt. One is an aphyric high-alumina basalt with the chemical characteristics of Northern Belt Division D high-alumina basalt: low TiO_2 (0.63 per cent), low P_2O_5 (0.10 per cent), and relatively high MgO (4.60 per cent), Ni (30 ppm) and Cr (40 ppm) (compare average Division D high-alumina basalt, Table 2). The second analysis is of a basaltic andesite (54.65 per cent SiO_2) with very low Ni and Cr (less than 8 ppm) but with moderate MgO (4.44 per cent); its association is unclear.

MISKWA LAKE PORPHYRITIC BASALTS

The Miskwa Lake porphyritic basalt suite, which outcrops between Wasekwan Lake and Sickle Lake, includes pyroxene-plagioclase-phyric, plagioclase-phyric and aphyric flow types. Some of these are superficially similar to McVeigh Lake porphyritic basalt although a lithologic correlation cannot be made. The chemistry of the Miskwa Lake suite (analyses 19 to 23) indicates that the chemical dissimilarities between the Miskwa Lake and McVeigh Lake basalts further demonstrate the absence of correlation between the two bodies. In summary the Miskwa pyroxene-plagioclase-phyric basalts contain less MgO, TiO_2 ,

P_2O_5 , Ni, Cr and Zr than the McVeigh Lake basalts (Tables A1 and A2, Appendix); note that apart from MgO these elements are the least likely to have been redistributed during alteration. On a plot of Zr vs. MgO the single trace element analysis available of Miskwa Lake porphyritic basalt plots well off the established Fox Lake-McVeigh Lake trend; the Miskwa Lake basalt in fact has affinities to Northern Belt Division D rocks, in its low contents of TiO_2 , P_2O_5 and Zr.

Chemical similarities exist between the various members of the Miskwa Lake basalt suite: note especially the characteristic low P_2O_5 , TiO_2 and Zr. Ni and particularly Cr contents are highest in the pyroxene-plagioclase-phyric basalt and are lowest in the aphyric basalts. If the entire suite is comagmatic the trend to lower Cr, MgO and CaO, and to higher SiO_2 from pyroxene-plagioclase-phyric basalt through plagioclase-phyric basalt to aphyric basalt might be explained by crystal fractionation of Cr-bearing pyroxene. Fractionation of this type has been documented within a single massive flow in the unit (Fig. 31).

The minor and trace element abundances in the Miskwa Lake basalt suite suggest affinities to the Northern Belt. With the limited data from the Keewatin River Belt suggesting a similar correlation, it thus appears that the Wasekwan Group rocks south of the Johnson shear zone may be akin to the Northern Belt and not the adjacent Southern Belt.

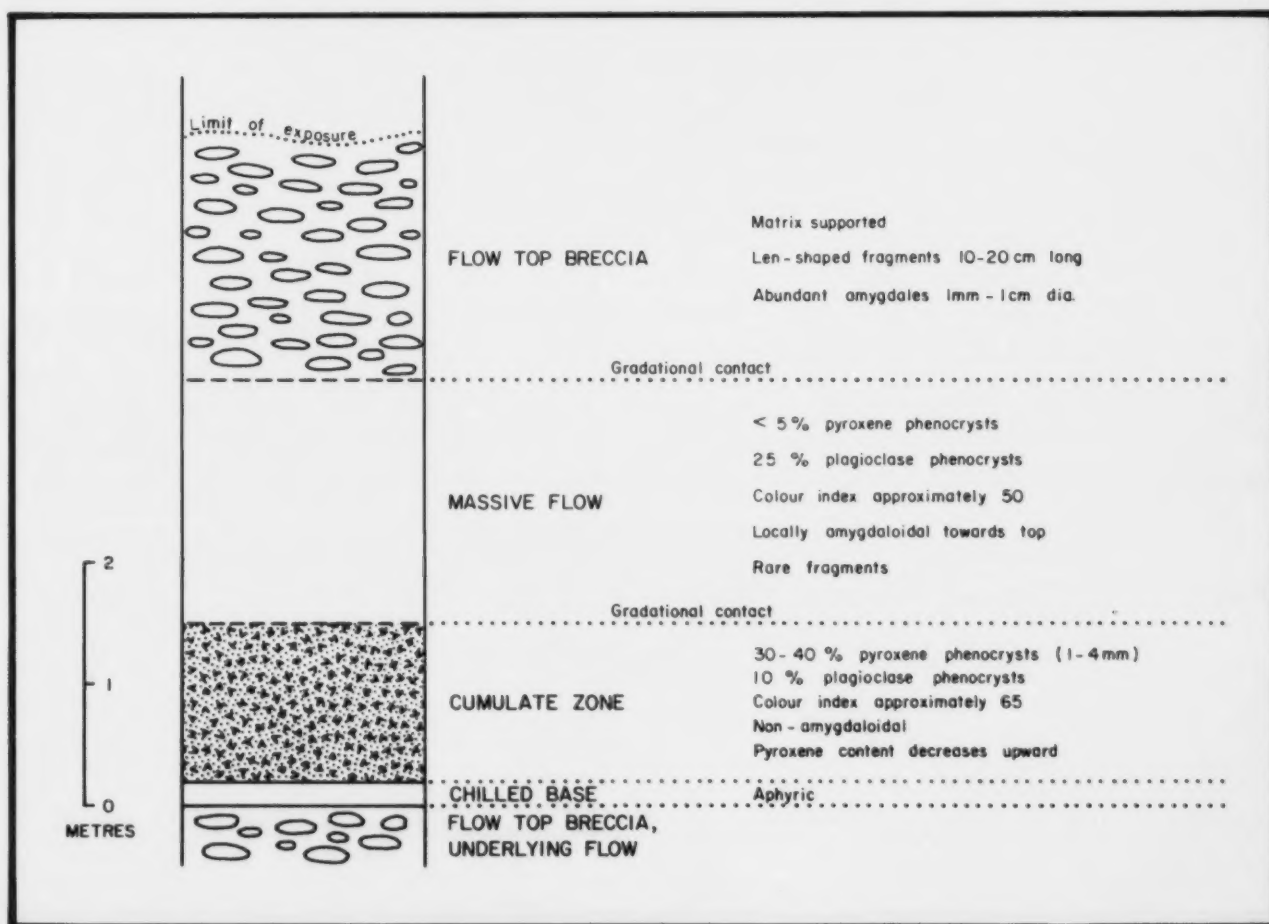


Figure 31: Differentiated porphyritic basalt flow, Miskwa Lake basalt.

WILMOT LAKE-NAIL LAKE BASALTS, ANDESITES

A belt of predominantly mafic breccia, flows and tuff occurs between Wilmot Lake and Franklin Lake. The succession is at least 1000 m thick and occupies a presumed synclinal structure; it is interpreted to be the youngest sequence in the Wasakwan Group on the west end of the Lynn Lake belt. The volcanic rocks conformably overlie the Fox Road turbidite southwest of Wilmot Lake and overlie Cockeram Lake basalt and McVeigh Lake basalt west of Franklin Lake. The succession is unconformably overlain by the Sickle Group at Wilmot Lake and is disconformably overlain by Sickle or Wasakwan conglomerate and greywacke at Gemmell Lake. Rock types in the belt comprise basaltic to andesitic breccia, intercalated thin flows, sedimentary rocks and, in the Gemmell Lake area, up to 15 per cent felsic flows and tuff. Some difficulty was experienced in sampling good volcanic flows, especially in the southwest part of the belt; consequently some of the analyses are of volcanic breccia and therefore are not necessarily representative of magmatic compositions.

Rocks from the southwest end of the belt (west of Wilmot Lake; analyses 141 to 148) display a wide range of FeO^*/MgO (Fig. 32) and do not appear to be equivalent to any of the major basalt bodies defined on Figure 11. At least some of the scatter on Figure 32 is due to alteration and analysis of breccia. The range of SiO_2 in these rocks is 45 to 60 per cent and the range of MgO is 15.16 to 2.26 per cent; there is a general decrease in MgO with increasing SiO_2 . On a Jensen plot (Fig. 33) the Wilmot Lake volcanic rocks display a tholeiitic trend. High Ni and Cr occur in high-MgO basalts (analyses 141, 148), but otherwise in basalts Ni averages 29 ppm and Cr averages 85 ppm; in andesites Ni averages 4 ppm and Cr averages 25 ppm. One basalt analysis shows high Al_2O_3 , but the TiO_2 content (1.52 per cent) is significantly greater than in any of high-alumina basalts in the Northern Belt (where TiO_2 is generally less than 1 per cent). Two samples from the Wilmot Lake suite display flat to mildly LREE-enriched REE patterns with La_{N} 17 to

31 times chondrite and negligible Eu anomalies (Fig. 34).

In the northeastern, Gemmell Lake-Franklin Lake portion of the belt the analyses (102 to 113) fall into two groups analogous to the grouping in the Northern Belt: (1) relatively magnesian (6.96-10.25 per cent MgO) basalts with low FeO^*/MgO ratios and "normal"-alumina contents (between 13 and 17 per cent), and (2) high-alumina (17.50-20.47 per cent Al_2O_3) basalts with low MgO and TiO_2 (analyses 106, 108, 111). The "normal"-alumina basalts have low TiO_2 contents (generally less than 1 per cent) and low FeO^*/MgO ratios but they plot outside the field defined by Northern Belt "normal"-alumina basalts on a TiO_2 - FeO^*/MgO diagram; they are closest in composition to Division D basalts (Fig. 35). On a plot of Al_2O_3 vs. MgO (Fig. 36) they have the high-MgO contents characteristic of Northern Belt Division D basalts. The high-alumina basalts have the major element chemical characteristics of Northern Belt Division B high-alumina basalts: they plot within the restricted field of Division B high-alumina basalts (Fig. 35), they have very low Ni and Cr contents, and low MgO contents. Nevertheless, sample 108 has almost the identical REE pattern of sample 80, a high-alumina basalt from Division D in the Northern Belt (Fig. 37).

In summary, the overall lithologic character of the Wilmot Lake-Nail Lake succession more closely resembles Northern Belt rocks than any of the lithologies elsewhere in the Southern Belt. Only in the northeastern portion of the belt, however, do the basalts have some of the chemical characteristics of Northern Belt basalts: there, high-alumina basalts with Division B major element characteristics and Division D REE patterns are associated with magnesian, "normal"-alumina basalts similar in some respects to Division D basalts. This ambiguous association precludes direct correlation of the Gemmell Lake-Franklin Lake section with either one of the major Northern Belt divisions, although the compositions are clearly Northern Belt type. None of the basalts at the Wilmot Lake end of the belt can be chemically correlated with the Northern Belt.

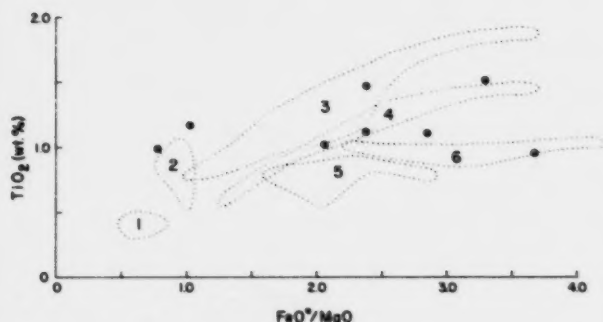


Figure 32: TiO_2 vs. FeO^*/MgO , Wilmot Lake volcanic rocks. Compositional fields shown for comparison are as in Fig. 11.

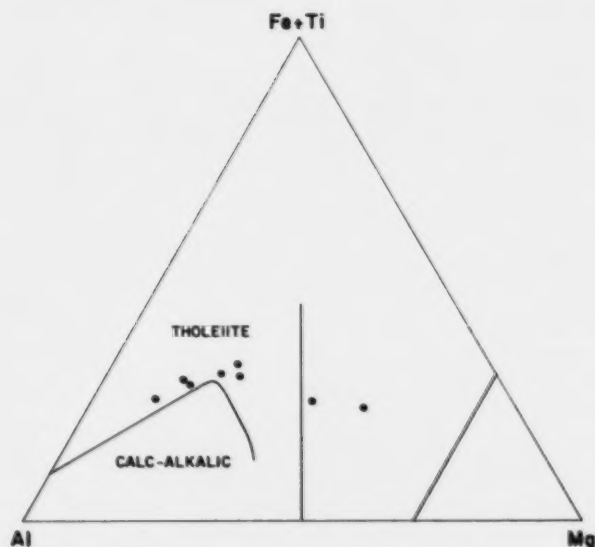


Figure 33: Jensen cation plot, Wilmot Lake volcanic rocks.

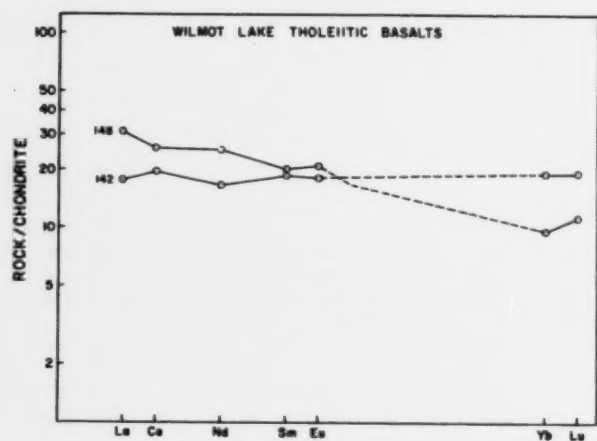


Figure 34: Chondrite normalized REE plot, Wilmot Lake volcanic rocks.

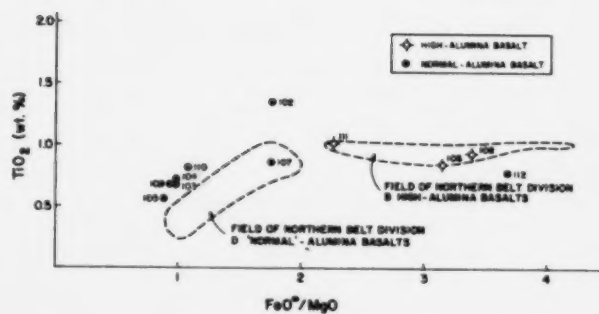


Figure 35: TiO_2 vs. FeO^*/MgO , Gemmell Lake-Franklin Lake basalts, and comparative fields of Northern Belt basalts.

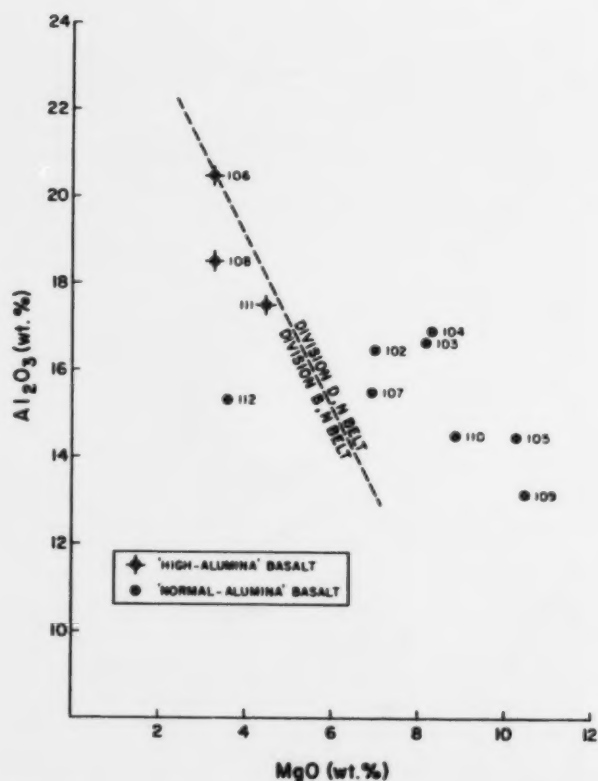


Figure 36: Al_2O_3 vs. MgO , Gemmell Lake-Franklin Lake basalts. Separation line between Northern Belt Divisions B and D shown for comparison.

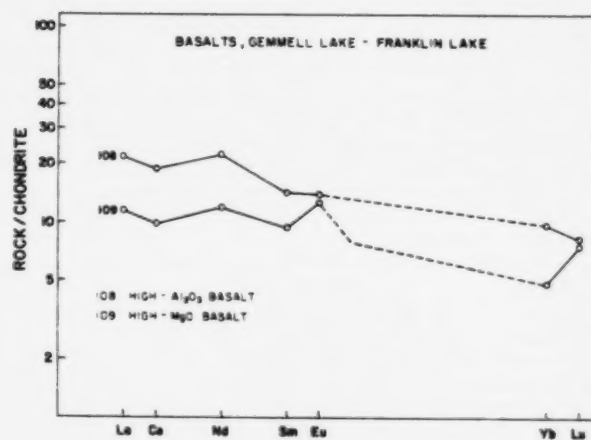


Figure 37: Chondrite normalized REE plot, Gemmell Lake-Franklin Lake basalts.

PRIMITIVE CALC-ALKALINE BASALTS

FOX LAKE AND McVEIGH LAKE PORPHYRITIC BASALT

Two separate bodies of a distinctive clinopyroxene-phyric basalt, the Fox Lake and McVeigh Lake bodies, occur in the Southern Belt. Both have been interpreted as small shield volcanoes. The porphyritic basalt at McVeigh Lake is coeval with the aphyric, Cockeram Lake quartz tholeiites; the Fox Lake, McVeigh Lake and Cockeram Lake bodies together form the basaltic substrate of the Southern Belt (Table 1). Close similarities between some members of the Fox Lake suite and the McVeigh Lake basalt provide the basis for stratigraphic correlation in the Southern Belt.

The Fox Lake and McVeigh Lake basalts are characterized by the abundance of large euhedral clinopyroxene phenocrysts (pseudomorphed by hornblende). Some of the more magnesian members in the Fox Lake body are essentially metapyroxenites. Crystal settling of pyroxene within single massive flows and even within individual pillows has produced pronounced phase and chemical differentiation (e.g. analyses 117 and 118; Fig. 38).

The Fox Lake and McVeigh Lake basalts both contain erratic and generally high contents of K_2O , Sr, Rb and Ba (Fig. 39). The trends of K_2O , CaO, Sr, Rb and Ba are parallel when plotted against MgO (Fig. 39), and there is no systematic variation of these oxides and elements with MgO content. The erratic variation of elements, unusually high contents of K_2O , Ba, Sr and Rb, and the parallelism of commonly antipathetic element trends (e.g. K_2O -CaO) suggests that the rocks have undergone significant LIL-element alteration. K-metasomatism is most common but some of the rocks have been Na-metasomatised. Why the porphyritic basalts should be particularly susceptible to alteration is unknown. Possibly the groundmass was partly or wholly vitric, which would be readily altered during sea-floor alteration. The production of clay minerals in the devitrified glass might account for the present abnormal variation of elements and the common occurrence of fine grained biotite in the recrystallized groundmass of these rocks.

On a plot of TiO_2 vs. FeO^*/MgO (Fig. 11) Fox Lake basalts form a tight cluster and McVeigh Lake basalts (not shown on Fig. 11) display only limited variation. The suite as a whole does not display the range in FeO^*/MgO expected if the basalts had tholeiitic affinities (cf. Cockeram Lake basalt, Tod Lake basalt). TiO_2 has an almost constant abundance (approximately 0.5-1 per cent) over the entire range in MgO (7.97-14.05 per cent). This probably indicates that Fe-Ti oxides crystallized and were steadily removed during fractionation, preventing concentration of Ti (and Fe) in successive differentiates.

The absence of a trend to iron enrichment is also apparent on an MgO vs. FeO^* plot (Fig. 40). If the entire suite is comagmatic and related by some process of differentiation (below) then it is not tholeiitic in character. Considering the complete absence of iron enrichment and the relatively magnesian nature of the suite, these rocks are termed "primitive" calc-alkaline in this report.

Fox and McVeigh Lake basalts have high Th contents (1.8-3.2 ppm) relative to tholeiitic basalts (less than 1 ppm). Elevated Th concentrations are also characteristic of the Hughes Lake calc-alkaline sequence (2.3-3.5 ppm). In the Fox-McVeigh suite, Th abundance increases with Zr (Fig. 41). The clear separation of tholeiitic and calc-alkaline rocks on the Th-Zr plot further serves to characterize the Fox-McVeigh suite as calc-alkaline.

Analyses from the Fox Lake and McVeigh Lake bodies plot along a linear trend on a Zr vs. MgO diagram (Fig. 42). Zr is generally accepted as one of the less mobile trace elements (e.g. Ludden et al., 1983) so this plot should provide more information on primary differentiation pro-

cesses than plots involving the much more mobile elements (alkalis, Ca, Ba, Rb, Sr; see below). The mobility of Mg during alteration has been demonstrated to occur in subaqueous basaltic rocks but the magnitude of that mobility in Wasekwan Group rocks generally cannot be estimated from inspection of the analyses. Important points to be made from the Zr vs. MgO diagram are:

(1) The linear relationship between Zr and MgO indicates only limited redistribution of Mg during alteration. If Mg had been irregularly redistributed then there would not be a systematic variation of Zr with MgO. Note that the other rock units in the Lynn Lake belt (e.g. Fig. 22) also show a systematic variation of Zr with MgO.

(2) The two separate bodies of porphyritic basalt (Fox and McVeigh) plot along the same trend line, strongly suggesting that they constitute a single magmatic suite related by some process of differentiation. This geochemical correlation provides support for the stratigraphic correlation (Table 1) which was based on mesoscopic field characteristics.



Figure 38: Pillowed Fox Lake porphyritic basalt. Pyroxene (pseudomorphed by amphibole) phenocrysts are concentrated in the lower part of the pillow.

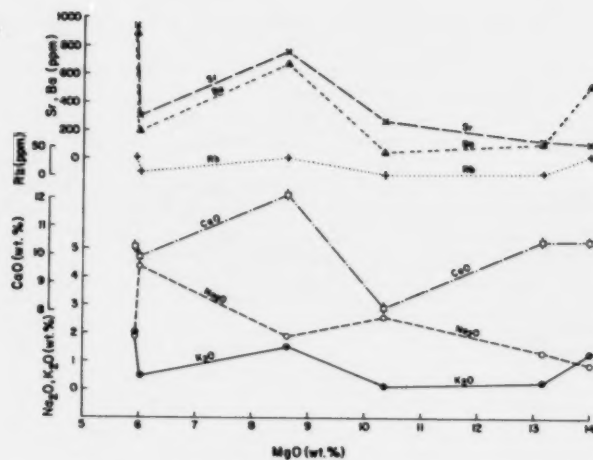


Figure 39: K_2O , Na_2O , CaO , Rb , Ba and Sr vs. MgO , Fox Lake and McVeigh Lake basalt. Note the non-systematic variation of these elements, indicating redistribution during alteration and metamorphism.

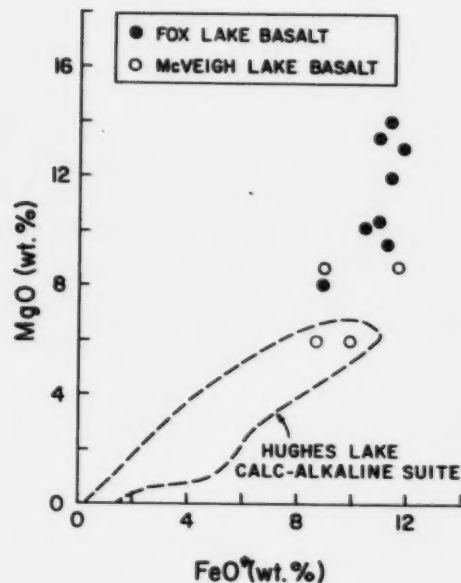


Figure 40: MgO vs. FeO^* , Fox Lake and McVeigh Lake basalt. These rocks are significantly more magnesian than the calc-alkaline basalt-andesite-dacite-rhyolite suite at Hughes Lake, but, like the calc-alkaline suite, they display no iron enrichment.

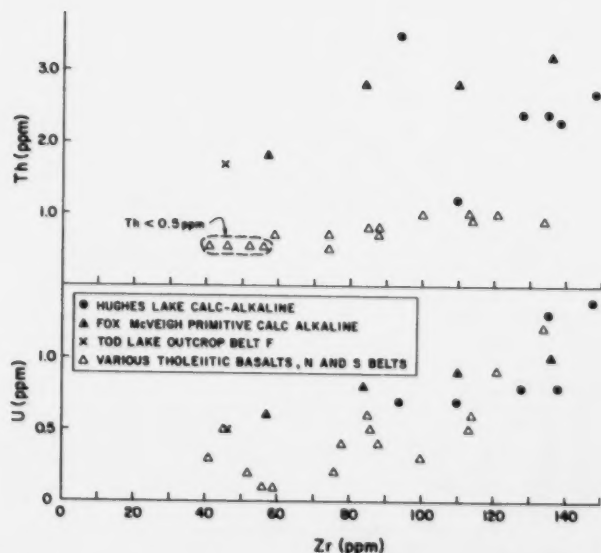


Figure 41: Th and U vs. Zr , Wasekwan Group. There is a clear separation into two fields on the Th - Zr plot, with tholeiitic rocks containing less than 1 ppm Th and calc-alkaline rocks containing greater than 1 ppm Th . The analysis from Tod Lake basalt outcrop belt F is sample 170, which displays a fractionated REE pattern (Fig. 13).

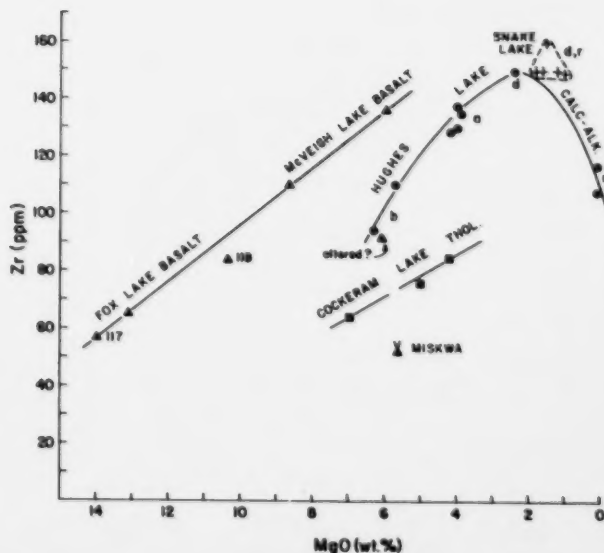


Figure 42: Zr vs. MgO , Fox Lake-McVeigh Lake basalt, Hughes Lake calc-alkaline suite, Snake Lake dacite, Cockerm Lake basalt, Miskwa Lake porphyritic basalt. b = basalt, a = andesite, d = dacite, r = rhyolite.

(3) Analyses of McVeigh Lake porphyritic basalt (except analysis 16, which may have suffered Mg redistribution) plot along the line joining analyses 117 and 118. The chemical variation between 117 and 118 is known to have been produced by pyroxene fractionation: analysis 117 represents the cumulate base of a differentiated pillow and analysis 118 represents the fractionated top of another differentiated pillow (Fig. 38). Thus the chemical variation in the entire suite appears to have been produced by pyroxene fractionation, a conclusion that is consistent with the pyroxene-phenocryst-rich nature of the basalts.

(4) Zr abundances in porphyritic basalt exceed those in all of the tholeiitic suites, for any given MgO level. Zr is an incompatible element in basaltic systems, and is concentrated in successive liquid fractions during differentiation. Thus the MgO-rich, high-Zr porphyritic basalts cannot have been derived from the tholeiitic magmas in the Lynn Lake belt; i.e. the Fox-McVeigh porphyritic basalts do not lie on the liquid line of descent of any of the tholeiitic suites.

(5) Zr values of the porphyritic basalts are **higher** than in basalts of the Hughes Lake calc-alkaline suite, suggesting that this calc-alkaline suite is **not** related to the Fox Lake-McVeigh Lake magmatic line of descent.

(6) Analyses of the Snake Lake dacite and rhyolite (which overlies Fox Lake porphyritic basalt) plot approximately along the projection of the Fox Lake-McVeigh Lake trend, suggesting that these unusual felsic rocks may be related to the porphyritic basalts by fractional crystallization.

(7) Miskwa Lake porphyritic basalt has a completely different Zr/MgO ratio than the Fox Lake-McVeigh Lake suite, indicating that the Miskwa Lake body cannot be correlated with superficially similar rocks at McVeigh Lake.

The Cr content of the Fox Lake-McVeigh Lake suite (178-2764 ppm) greatly exceeds that in other basalt units in the Lynn Lake belt (e.g. Cockeram Lake tholeiitic basalt: 10-230 ppm Cr). Cr content declines dramatically with decreasing MgO whereas Ni shows only a modest decrease over the same MgO range (Fig. 43). Note that the pyroxene cumulate (analysis 117) contains more than twice the Cr than the fractionated portion of a pillow (analysis 118). Chromiferous oxides

are not present in the cumulate so the variation in Cr content must be related to crystal settling of Cr-bearing clinopyroxene. Relatively low Ni contents, even in cumulate rocks of the suite, indicate that olivine was not a fractionating phase. The chemical variation displayed by the Fox Lake-McVeigh Lake porphyritic basalts therefore can be best explained by the precipitation of clinopyroxene from successive differentiates.

McVeigh Lake porphyritic basalts have strongly fractionated REE patterns (Fig. 44) despite their relatively high MgO contents (6-9 per cent). These basalts have La_N/Yb_N ratios of 7.6-7.9, La_N of 76 times chondrite and no Eu anomalies. They are in fact slightly more fractionated than Hughes Lake calc-alkaline andesites. The REE data is consistent with the Zr data (No. 5 above), indicating that the Fox-McVeigh basalts did not fractionate to produce the Hughes Lake calc-alkaline suite: i.e. despite their "primitive" (high-MgO) nature the Fox-McVeigh basalts were not parental to the Hughes Lake suite.

The Fox Lake porphyritic basalt samples are more magnesian (10-14 per cent MgO) than the McVeigh basalts and show correspondingly lower REE contents (La_N about 21 times chondrite) and lower La_N/Yb_N ratios (2.2-2.3). They too have negligible Eu anomalies. Sample 117, the pyroxene-cumulate base of a differentiated pillow, has lower middle REE contents than sample 118, which represents the top of a differentiated pillow.

The absence of Eu anomalies in the Fox Lake and McVeigh Lake basalts indicates that plagioclase was not a fractionating phase during differentiation. This is consistent with the major and trace element variation, and the absence of plagioclase phenocrysts in the lava flows.

A Recent, possible analogue of the "primitive" calc-alkaline suite in the Lynn Lake belt occurs in the Mariana island arc and is described by Dixon and Stern (1983). The most primitive lavas collected from the Mariana arc are submarine flows that are magnesian (8 to 9 per cent MgO, e.g. Table A6, Appendix) and lie on the Fe-Mg trend defined by calc-alkaline subaerial basalt and basaltic andesite lavas on adjacent islands. All of the lavas of this group are characterized by a lack of iron enrichment. The Mariana samples differ from the Fox-McVeigh basalts in that they have lower bulk REE abundances (Ce_N about 13 times chondrite); however they have Ce_N/Yb_N ratios similar to the Fox Lake basalts.

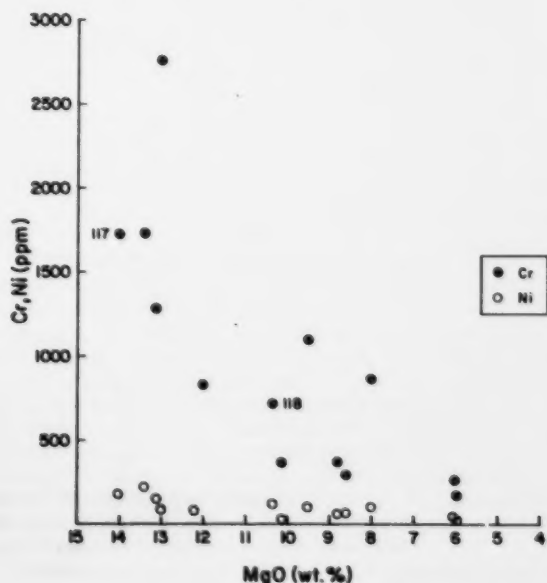


Figure 43: Cr and Ni vs. MgO, Fox Lake and McVeigh Lake basalt.

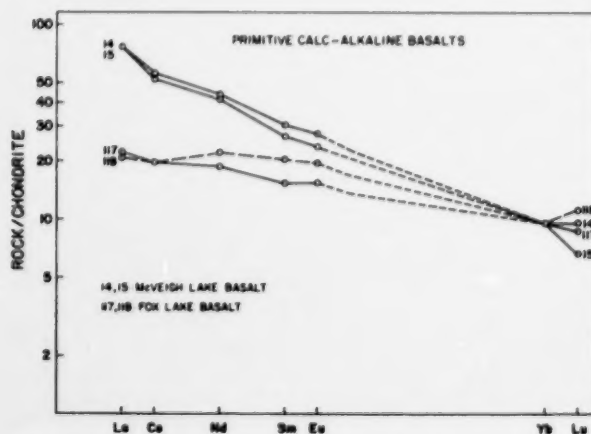


Figure 44: Chondrite normalized REE plots, Fox Lake and McVeigh Lake basalt ("primitive" calc-alkaline suite).

HUGHES LAKE CALC-ALKALINE BASALT, ANDESITE

The Hughes Lake calc-alkaline suite as defined here occurs in three geographic segments (Table 3): the Pole Lake, Hughes Lake and Chepil Lake areas. Chemical data are available predominantly from the better exposed Pole Lake and Hughes Lake segments. The calc-alkaline suite overlies Cockeram Lake quartz tholeiite at Cartwright Lake and is overlain by Hughes Lake olivine-normative transitional basalts east of Stan Lake. The true stratigraphic thickness of the calc-alkaline sequence is unknown because of the absence of complete sections through the entire suite; both the Pole Lake and Hughes Lake segments are at least 2500 m thick.

All of the rocks from the Hughes Lake segment of the suite have been Na-metasomatised whereas most Pole Lake andesites, although altered to some extent, plot within Hughes (1972) "igneous spectrum". Abundances of the mobile trace elements Ba, Rb and, to a lesser extent, Sr are somewhat erratic and are locally enriched, although the variation between samples is much smaller than in strongly altered rock suites (e.g. Fox Lake-McVeigh Lake basalt).

On an AFM diagram (Fig. 45) the suite defines a typical calc-alkaline trend across the ternary towards the alkali corner, without iron enrichment. The plotted position of an analysis on an AFM diagram is sensitive to the content of the mobile elements Na and K, so this plot alone cannot be used to define the suite as calc-alkaline. On TiO_2 vs.

FeO^*/MgO (Fig. 46), MgO vs. FeO^* (Fig. 47), and Jensen (Fig. 48) diagrams, however, the absence of iron enrichment clearly identifies the suite as calc-alkaline. Petrographically the rocks are noted for the common occurrence of phenocrysts (plagioclase, amphibole pseudomorph after pyroxene, quartz) in a groundmass of plagioclase microlites and amphibole and/or chlorite; oxide grains or leucosene pseudomorph after Fe-Ti oxides are disseminated through some samples but the general abundance of oxides is low.

The Pole Lake sequence is predominantly andesitic but progresses to somewhat higher SiO_2 upwards through the section: the uppermost exposed member is plagioclase-quartz-phyric andesite and dacite. Rhyolite flows and tuff are minor components and are scattered throughout the sequence. The Hughes Lake segment is dominated by the thick, mafic Lower Series basalts and basaltic andesites (Table 3). From base to top the Lower Series displays constant $FeO^*/(FeO^* + MgO)$ and slight but steady decrease in Ni and increase in TiO_2 (Fig. 26). In the overlying Upper Series andesites there is a steady decrease in FeO^* , declining but erratic MgO and TiO_2 , and nearly constant Ni upwards through the unit. The Hughes Lake section is topped by local rhyolite, polymictic conglomerate and fine grained sedimentary rocks. The contact with the overlying olivine-normative transitional basalts is abrupt (Fig. 26).

Table 3:
Summary of components comprising the Hughes Lake calc-alkaline suite.

Table 3

POLE LAKE AREA		HUGHES LAKE AREA		CHEPIL LAKE AREA	
LITHOLOGY	THICKNESS (m)	LITHOLOGY	THICKNESS (m)	LITHOLOGY	THICKNESS (m)
- Top not exposed -		Felsic tuff, minor rhyolite	700	- Top not exposed -	
CALC-ALKALINE SUCCESSION		Conglomerate, greywacke	200	CALC-ALKALINE SUCCESSION	
Porphyritic dacite, andesite; minor rhyolite	600	Transitional basalt	1060	Laharic breccia, tuff; minor andesite	500?
Plagioclase-phyric and aphyric andesite, pyroclastic breccia, tuff; minor rhyolite	900	CALC-ALKALINE SUCCESSION		Rhyolite, aphyric and porphyritic andesite	500
Aphyric and porphyritic andesite, tuff, rhyolite; minor greywacke, siltstone	1200	UPPER SERIES		Massive and pillowed basalt (possibly equivalent to Hughes Lake LOWER SERIES)	800?
Cockeram Lake aphyric basalt (tholeiitic)	2100 (max)	Pebble conglomerate, pebbly mudstone, siltstone, rhyolite	Local	- Base not exposed -	
		Plagioclase-phyric and aphyric andesite, flow breccia, tuff; subordinate basalt	500		
		LOWER SERIES			
		Aphyric and porphyritic basalt, basaltic andesite; local greywacke, siltstone, pebbly mudstone, laharic breccia	1950		
		- Base not exposed -			

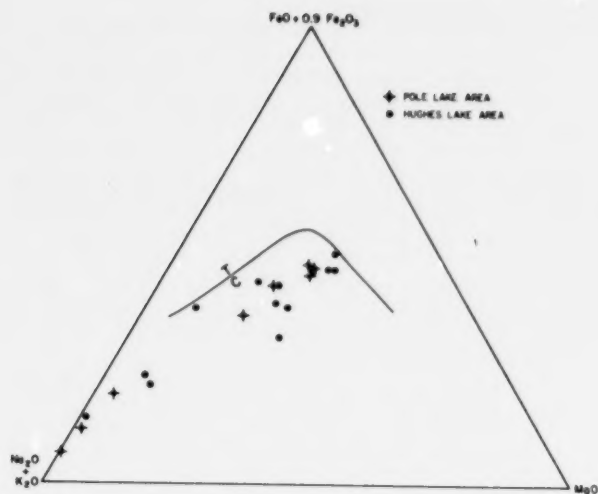


Figure 45: Ternary igneous AFM diagram, Hughes Lake calc-alkaline suite. Dividing line separating the tholeiitic field (T) from the calc-alkaline field (C) is from Irvine and Baragar (1971).

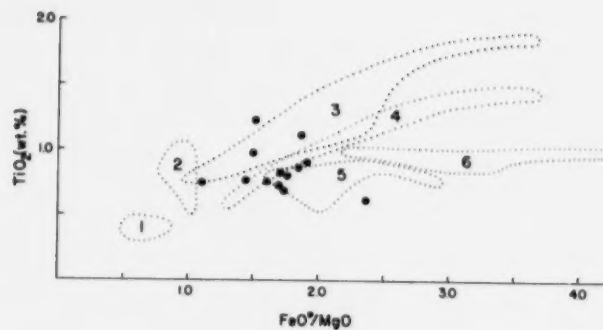


Figure 46: TiO_2 vs. FeO^*/MgO , Hughes Lake calc-alkaline suite. Note that the data points define a cluster with limited range of FeO^*/MgO , in contrast to the linear distributions defined by tholeiitic suites (e.g. Tod Lake basalt, 3; Cockeram Lake basalt, 4). Compositional fields for comparison are as in Fig. 11.

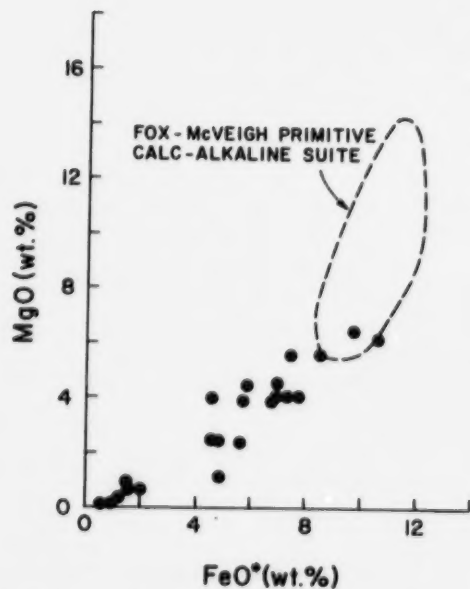


Figure 47: MgO vs. FeO^* , Hughes Lake calc-alkaline suite. There is a complete lack of iron enrichment through the compositional range of basalt to rhyolite.

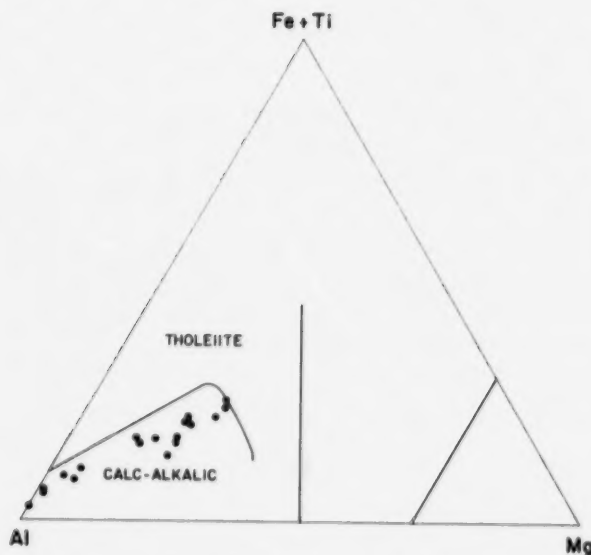


Figure 48: Jensen cation plot, Hughes Lake calc-alkaline suite.

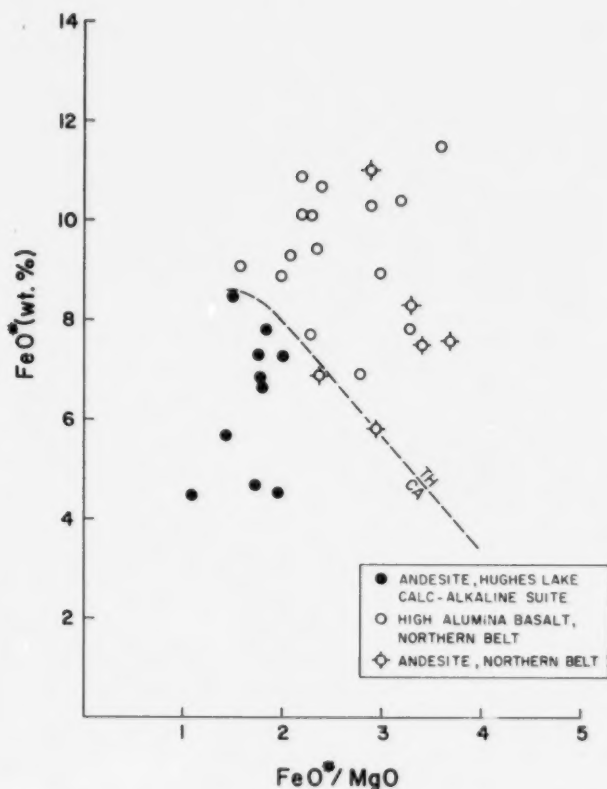
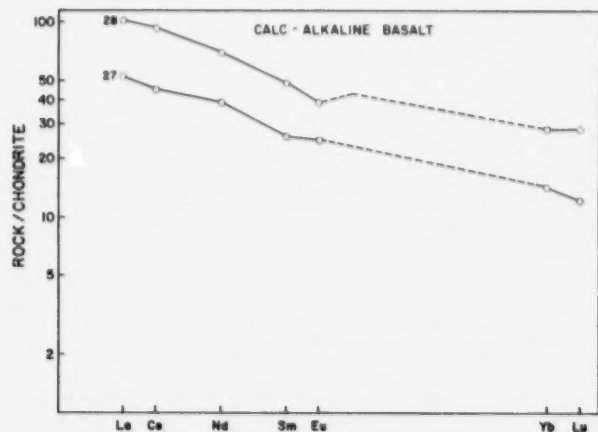


Figure 49: FeO^* vs. FeO^*/MgO , Hughes Lake calc-alkaline andesite and Northern Belt basalt, andesite. Dividing line between tholeiitic (TH) and calc-alkaline (CA) fields is after Miyashiro (1974).



Andesites in the Pole Lake and Hughes Lake segments differ in stratigraphic setting, unit thickness and petrography yet they are very similar in major element composition and content of the least-mobile trace elements TiO_2 , P_2O_5 , Ni, Cr and Zr (Tables A1 and A2, Appendix) and REE elements (Table A3, Appendix). Rocks from the entire suite plot on a single trend on a Zr vs. MgO diagram (Fig. 42), with a Zr maximum in the dacite compositional range. This suggests that the geographically and stratigraphically segmented members of the Hughes Lake calc-alkaline suite belong to a single line of magmatic evolution presumably linked by some process of differentiation. The decline in Zr content between dacite and rhyolite (Fig. 42) probably reflects the crystallization of zircon in magmas slightly more siliceous than dacite, precluding further Zr enrichment in felsic differentiates.

A close compositional similarity exists between the andesite lavas and a group of fine grained quartz diorites (sample 61; unit 14, Gilbert et al., 1980). These fine grained intrusions, which are observed **only** within the Hughes Lake suite, are interpreted as synvolcanic plugs; i.e. andesitic magma which was not extruded, but emplaced within the superstructure of the calc-alkaline stratovolcano.

There are major differences between the Hughes Lake andesites and Northern Belt Division B andesites. The calc-alkaline Hughes Lake andesites have lower Al_2O_3 , FeO^* , CaO, FeO^*/MgO , Mg/Ni and higher MgO, K_2O , P_2O_5 , Ni, Cr, Zr, Ba and V than Division B andesites (Tables A1 and A2, Appendix; Fig. 49). The contrast in Ni and Cr is particularly striking: the low Ni and Cr of Division B andesites is characteristic of basaltic rocks in the Northern Belt as a whole and Division B in particular. On the Zr vs. MgO plot (Figs. 22, 42) andesites from the Hughes Lake suite and Division B plot in separate fields; the Hughes Lake andesites are part of the general Hughes Lake basalt-andesite-dacite-rhyolite trend whereas Division B andesites are at the high-Zr end of the Division B basalt-andesite trend. Clearly the andesites from the two areas are not parts of a single line of magmatic evolution. Northern Belt Division B andesites are intermediate differentiates in a high-alumina "arc tholeiite"-type suite and Hughes Lake andesites are the dominant members of a differentiated calc-alkaline suite. The dichotomy between the Northern Belt (high-alumina tholeiites) and the Southern Belt (bimodal tholeiite and calc-alkaline) therefore extends at least to andesites from the two belts.

The individual REE patterns of calc-alkaline basalt, andesite and low- SiO_2 dacite are virtually identical (except for sample 28, a strongly fractionated basalt; Figs. 50a and 50b). The REE patterns are smoothly concave upwards and show marked LREE enrichment ($\text{La}_N/\text{Yb}_N = 3.6$ to 6.0) with La_N 48 to 63 times chondrite. HREE too are relatively high

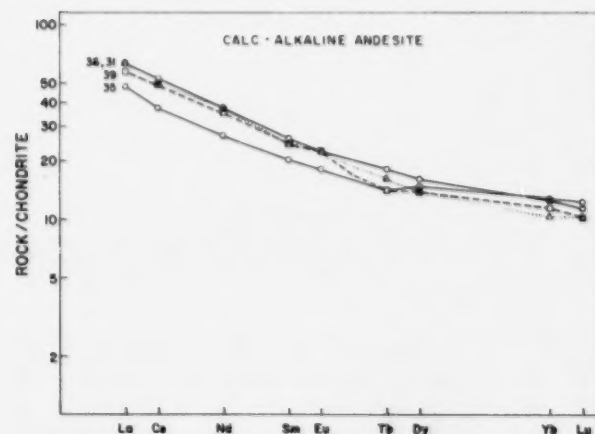


Figure 50: Chondrite normalized REE plots, Hughes Lake calc-alkaline basalt (a) and andesite (b).

(about 11 times chondrite). Eu anomalies are negligible. The absence of REE enrichment between basalt ($\text{SiO}_2 = 53.70$ wt. per cent, sample 27) and dacite ($\text{SiO}_2 = 62.05$ wt. per cent, sample 39) is remarkable given the major, minor and trace element gradients which exist between the two.

GEOCHEMICAL AFFINITY OF THE CALC-ALKALINE SEQUENCE

Orogenic andesites can be broadly subdivided on the basis of their tectonic setting. Island arc-type and continental margin-type andesites are characteristic of consumptive plate margins in regions of thin, oceanic crust and thick, continental crust, respectively. Volcanic rocks in these two settings can be distinguished by their major, minor and trace element chemistry (e.g. Gunn et al., 1974; Gunn, 1976; Ewart, 1976). Table 4 summarizes the average compositions of andesites from the Proterozoic Hughes Lake suite, Archean greenstone belts, and Cenozoic island arc and continental margin environments. Data from the Mariana arc is included because it is a prime example of an "intra-oceanic" arc far removed from continental margins. Hughes Lake andesites are similar to both island arc and continental margin andesites in SiO_2 , Al_2O_3 , FeO^* and MgO . They are similar to continental margin

andesites in P_2O_5 and MnO , similar to island arc andesites in K_2O^* , TiO_2 , Sr, Rb, Ba and Y, and are intermediate in La_N/Yb_N ratio and CaO. The Hughes Lake suite has higher Ni and Zr contents than either arc-type or continental margin-type andesites.

The individual Cenozoic averages listed in Table 4 necessarily incorporate a large volume of data from a number of different geographic areas and do not display the range of compositions which occur in individual island arcs and continental margins. For example, "high- K_2O^* " andesites with La_N/Yb_N ratios and Zr concentrations similar to the Hughes Lake suite occur in the intra-oceanic New Hebrides arc (Gorton, 1977), and calc-alkaline rocks similar in composition to island arc volcanics occur in the Central Andes, in a belt closest to the Peru-Chile trench (Dostal et al., 1977). The Hughes Lake calc-alkaline suite, despite its distinctive chemical character (which reflects its own unique source P-T conditions and subsequent differentiation history), is more closely akin to island arc than continental margin composition.

*Note that the very low average K_2O content (0.59 per cent) is strongly influenced by the Na-metasomatized nature of the Hughes Lake segment rocks. The range of K_2O for the entire suite is 0.20-0.99 per cent.

Table 4:
Average compositions of Hughes Lake and other andesite suites.

Table 4

	Hughes Lake		Island Arc		Continental Margin		Cont. Int.	Archean		
	1	2	3	4	5	6	7	8	9	10
SiO_2	58.12	58.01	57.12	59.20	58.93	59.61	61.84	57.77	56.2	56.9
Al_2O_3	16.59	16.80	17.43	16.82	16.82	17.12	16.63	17.30	16.1	16.1
Fe_2O_3	1.54		3.04	2.90	2.71	2.46	6.11	8.28		1.8
FeO	5.06	7.33	5.08	4.50	4.26	3.85			9.15	5.2
CaO	7.30	8.35	8.42	6.88	6.64	6.15	4.52	5.93	6.84	5.7
MgO	3.89	3.93	3.86	3.20	3.93	3.11	1.91	4.73	4.18	4.2
Na_2O	4.11	3.35	3.09	3.30	3.57	3.97	3.80	4.06	4.10	3.65
K_2O	0.59	0.92	0.93	1.29	1.87	1.63	3.90	0.88	0.82	0.95
TiO_2	0.76	0.76	0.74	0.76	0.92	0.92	0.94	0.90	0.93	0.82
P_2O_5	0.24	0.17	0.14	0.17	0.21	0.27	0.32	0.13		0.16
MnO	0.12	0.17	0.17	0.14	0.14	0.11	0.08	0.13	0.11	0.13
H_2O	1.48			0.87		0.84				2.87
S	0.03									
CO_2	0.21									0.66
Rb	9	16	31		61			26		
Sr	375	367	281		472			184		173
Ba	250	307	179		450					218
Zr	136	82								
Y	25	24								
Ni	59	16	29		31			102	115	67
Cr	64	38	32		127				70	89
La_N/Yb_N	4.93	1.79			11.47 ¹¹					

- 1 Hughes Lake calc-alkaline andesite; analyses 30-36, 38.
- 2 Island arc calc-alkaline andesite (Sarigan Island, Mariana Arc; Meijer and Reagan, 1981: calculated from Table 6a, p. 346-347; $n = 14$).
- 3 Island arc andesite (Gunn et al., 1974: Table 3, p. 1027).
- 4 Island arc pyroxene andesite (Ewart, 1976: Table 1, p. 420).
- 5 Continental margin andesite (Gunn et al., 1974: Table 3, p. 1027).
- 6 Western American (continental margin) pyroxene andesite (Ewart, 1976: Table 1, p. 420).
- 7 Continental interior andesite (Gunn et al., 1974: Table 3, p. 1027).
- 8 Archean high-alumina andesite (Gunn, 1976: average of Columns 62 and 30, Table 1, p. 392).
- 9 Abitibi Belt calc-alkaline andesite (Jolly, 1975: Table 1, p. 206).
- 10 Abitibi Belt calc-alkaline andesite (Goodwin and Smith, 1980: Table 1 and 2, p. 305-306).
- 11 Ratio calculated from data of Dostal et al. (1977).

RHYOLITE, DACITE

Felsic volcanic rocks in the Lynn Lake greenstone belt include massive aphyric and porphyritic flows and sills, felsic breccias, and tuff. All of the analyzed felsic rocks are of massive rhyolite or dacite, except for one dacite tuff from the Keewatin River body and two tuffaceous rocks from the Snake Lake bodies.

Felsic rocks in the Southern Belt occur stratigraphically above the basaltic substrate comprising the Fox Lake, McVeigh Lake and Cockeram Lake basalts. The felsic bodies in the Southern Belt which have been analyzed are the Snake Lake dacite/rhyolite (in the Fox Mine area) and the Cartwright Lake rhyolite (part of the Hughes Lake calc-alkaline sequence). A small body of rhyolite which outcrops 2 km northeast of Gemmell Lake was analyzed for trace elements. In the Northern Belt felsic rocks occur in Divisions A, B, C, D and F: all of the trace element analyses are from the large body of porphyritic rhyolite south of Lynn Lake town (Division A). Plagioclase-phyric dacite from the Keewatin River belt was also analyzed.

SNAKE LAKE DACITE, RHYOLITE

The felsic volcanic rocks comprising the Snake Lake dacite occur at the top of the Fox Lake porphyritic basalt and within the overlying sequence of porphyritic and aphyric basalts (Fox Mine succession). They are locally directly overlain by sedimentary rocks. The dacite occurs as aphyric and plagioclase-phyric massive flows (and dome?), autoclastic breccias, and tuff. A stratigraphic analysis of the various bodies (Fig. 51) suggests that with time there was an increase in silica content of the magma and an increase in the proportion of pyroclastic to massive rocks.

SiO₂ content of the suite ranges from 66.85-73.10 per cent and MgO from 1.81-0.13 per cent; generally MgO decreases with increasing SiO₂. Three samples (137, 138 and 139) are weakly anomalous in MgO for their SiO₂ level, possibly indicating high temperature hydrothermal alteration and weak Mg enrichment. Samples 137 and 138

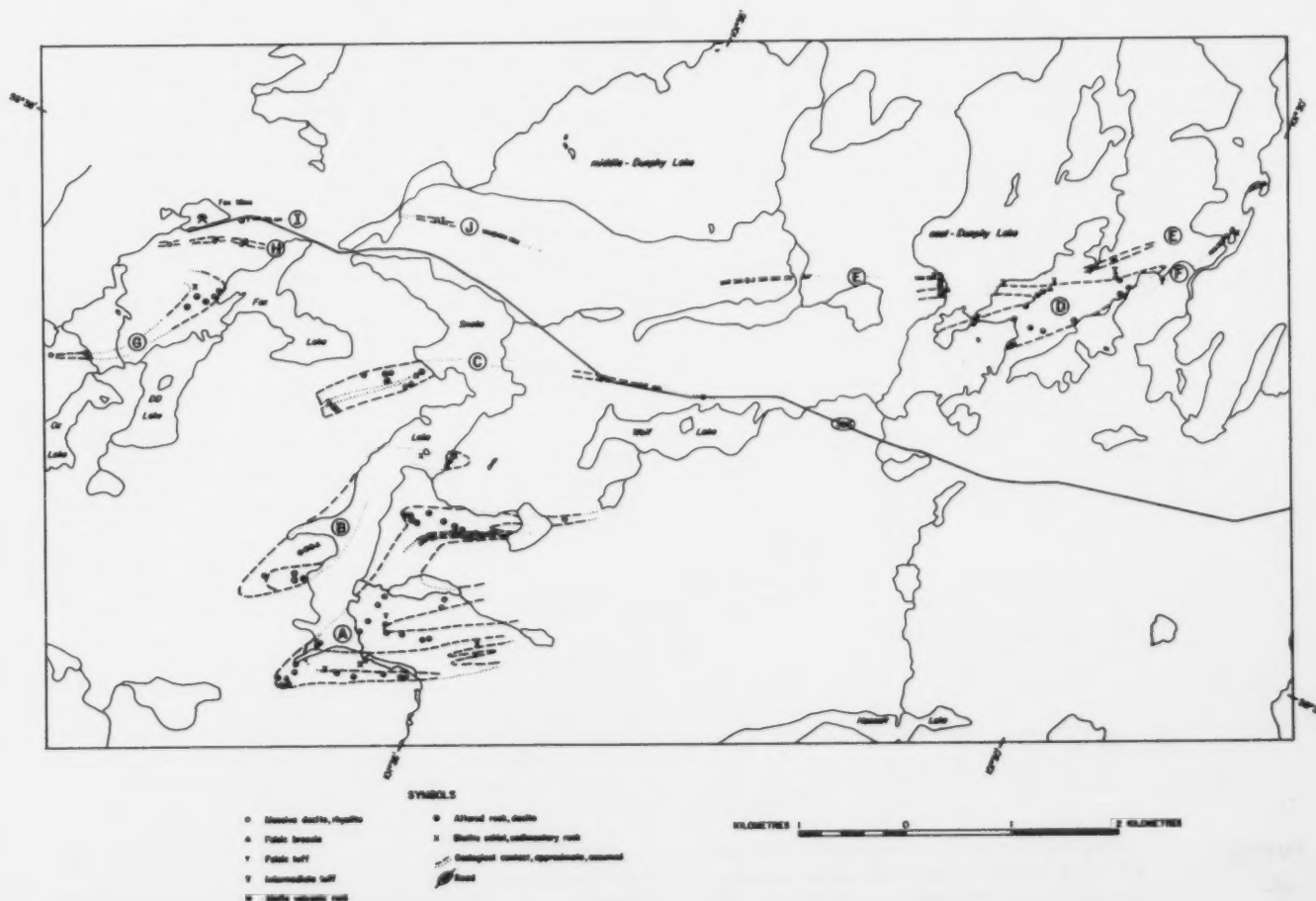


Figure 51: Location of Snake Lake dacite bodies.

were taken approximately 100 m south of the Fox Lake orebody (in the hanging wall) and 139 was taken 2 km along strike to the east. Isolated layers of anthophyllite schist, possibly exhalite, occur nearby. Total alkalis in the suite range from 4.60-7.45 per cent; the dacites have K_2O/Na_2O ratios greater than one whereas the rhyolites have K_2O/Na_2O ratios less than one. These elements have clearly been redistributed during moderate to intense K- and Na-metasomatism. The rocks with the largest Na_2O content (lowest K_2O/Na_2O ratios) are stratigraphically highest and are overlain by marine sediments; these tuffaceous rocks may have undergone chemical exchange with seawater to produce the striking Na enrichment. Porphyroblastic schists, some containing anthophyllite and cordierite, represent large portions of the dacite in the Fox Mine-Snake Lake area. They are interpreted as hydrothermally altered dacite related to the Cu-Zn mineralization in the area.

There is a positive correlation between the abundances of MgO, Cr and V in the Snake Lake suite (if the sample of tuff (analysis 139) is excluded: note that tuff is much more susceptible to alteration than massive material). On a triangular plot of Zr-V- $Y \times 3$ (Fig. 52) the analyses of massive dacite plot along a line of constant Zr/Y.3 ratio, indicating fractionation of a V-bearing phase. Cr and V substitute for Fe^{3+} in magnetite and pyroxene so it is probable that the sympathetic variation of MgO, Cr and V reflects fractionation of pyroxene. Recrystallized ferromagnesian phenocrysts comprise 10 per cent of the massive dacite and rhyolite, indicating that a mafic mineral such as pyroxene was a liquidus phase in the magma prior to or during eruption. On a Zr vs. MgO plot Snake Lake dacites plot along the projection of the trend line defined by the Fox Lake and McVeigh Lake porphyritic basalts: note that all other analyzed felsic rocks plot well off this projection. Thus it appears possible that the pyroxene fractionation which gave rise to the porphyritic basalt suite ultimately produced the Snake Lake dacites and rhyolites.

The REE patterns of Snake Lake felsic rocks (Fig. 53) display a decrease in LREE concentration between dacite (67.85 per cent SiO_2) and rhyolite (71.90 per cent SiO_2). This type of relationship is common in felsic rocks (Miller and Mittlefehldt, 1982). Miller and Mit-

tlefehldt (1982) propose that the LREE do not act as incompatible elements in highly felsic magmas, and that the depletion involves separation of minute quantities of an extremely LREE-rich accessory mineral, probably either monazite or allanite.

RHYOLITE

Rhyolite flows and sills ranging in size from small isolated bodies to the large felsic complex south of Lynn Lake town (Baldwin, 1983) are relatively common in the Northern Belt and in the Gemmell Lake portion of the Southern Belt. Elsewhere in the eastern portion of the Southern Belt rhyolite occurs only in the Hughes Lake calc-alkaline suite. There is little in the major element chemistry to distinguish between the various rhyolite bodies. Minor differences are noted in SiO_2 content (probably reflecting local silicification for those rhyolites with more than 78 per cent SiO_2), K_2O/Na_2O ratio (probably reflecting redistribution of alkalis during Na- and K-metasomatism; Fig. 6), and TiO_2 content (discussed below).

Trace element analyses provide inexpensive, rapid and effective discriminants to distinguish between the various rhyolite bodies and provide a unique chemical "fingerprint" for each (Fig. 54). Zr and Ti are the best discriminants because they display the least variation within the different bodies and the range of variation shows negligible overlap between bodies. Average V and Y contents also are good discriminants but the range of variation overlaps slightly between some of the bodies (i.e. Gemmell and Lynn for V, Lynn and Snake for Y). Ni is almost constant throughout the four bodies but is slightly elevated in the Gemmell Lake rhyolite.

The remaining trace elements are less useful as chemical discriminants. Sr, Rb and Ba contents are variable within and between different rhyolites, suggesting local redistribution of these elements. The Gemmell, Cartwright and Snake Lake rhyolites form tight groups and are separable on a Zr-Sr-Rb diagram (Fig. 55), whereas the Lynn Lake rhyolite shows considerable variation (a function mainly of variable Sr content). Pb contents are generally low (0-6 ppm) but anomalously high values (up to 27 ppm) occur in the Lynn and Cartwright rhyolites. Zn is similarly locally enriched in some samples relative to the average for individual bodies; the highest value (271 ppm) is in the Lynn Lake rhyolite. Cu contents are relatively constant, generally 9-20 ppm in the Gemmell, Lynn and Snake Lake bodies and 3-10 ppm in the Cartwright Lake body.

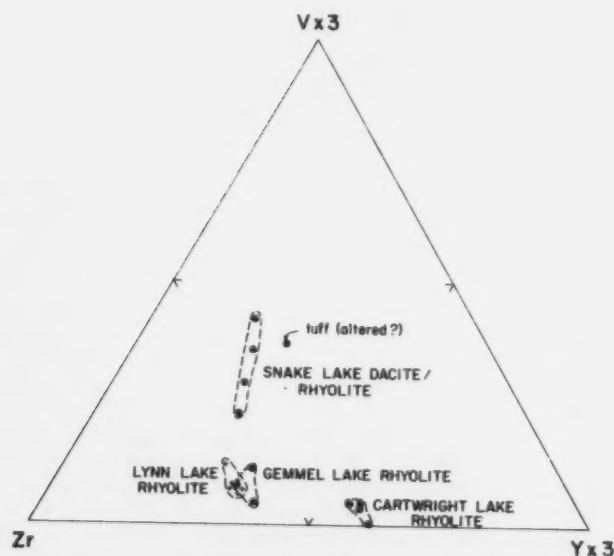


Figure 52: Ternary Zr-(V x 3)-(Y x 3) plot, rhyolites and dacites. Each felsic body has a unique trace element signature (see also Fig. 54). The Snake Lake dacites plot along a line of constant Zr:Y x 3 ratio.

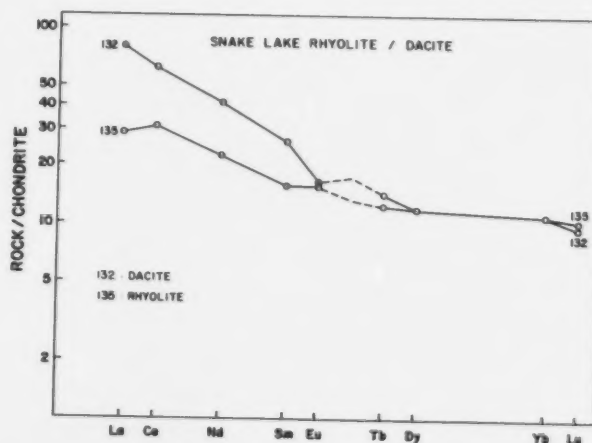


Figure 53: Chondrite normalized REE plots, Snake Lake dacite and rhyolite.

The trace element variation in the Lynn Lake rhyolite complex is probably due in part to its composite nature, inasmuch as this large body is composed of a sequence of pyroclastic rocks and subordinate flows (Baldwin, 1983).

The unique trace element chemistry of the different felsic bodies suggests that it may be possible to correlate these with other felsic bodies for which fewer data are available. For example, the contents of Zr, V, Y, Ni and Ti in a rhyolite occurring at the top of the Hughes Lake Upper Series (analysis 45, Table A1, Appendix) are directly comparable to the contents of these elements in the Cartwright Lake rhyolite (analysis 42), even though these rhyolites are physically and stratigraphically separate and are related only in that they both occur within the Hughes Lake calc-alkaline suite. This excellent correlation suggests that rhyolites within a particular magmatic suite may have similar trace element abundances.

The fact that each body of felsic rocks (or perhaps those within a particular magmatic suite) has a unique trace element distribution places some constraints on the generation of the magmas which produced those rocks. Hildreth (1979) and Smith (1979) show that trace element gradients are steep within compositionally zoned felsic magma chambers and, for the elements considered here, the following patterns are established: Ba, Sr and Mg are depleted in the roof zone, Y and Rb are enriched in the upper part of the chamber, and Zr, Ti, Fe and Cu are enriched downward in the chamber.

Rhyolites in the Lynn Lake belt show no evidence of being derived from a single compositionally zoned magma chamber; moreover, a weak positive correlation exists between Y and Zr for the Snake, Lynn and Gemmell Lake bodies (Fig. 56) rather than the negative trend as shown for single magma chambers (Hildreth, 1979). The unique trace element distributions of Wasekwan Group rhyolites imply that the different rhyolites were derived from (a) partial melts of different source rocks, (b) partial melts of an inhomogeneous source, or (c) fractionation in separate magma chambers, with the trace element concentrations a function of both the initial composition of the parent magmas and the effects of the dominant fractionation process (Smith, 1979).

RARE EARTH ELEMENT GEOCHEMISTRY

The REE concentrations in felsic volcanic rocks of the Lynn Lake belt provide, like the trace elements described above, excellent "finger-prints" of the various rhyolite bodies (Figs. 57a to c). Calc-alkaline rhyolites from the Hughes Lake suite have flat patterns ($La_N/Yb_N = 1.4$, 1.8) with pronounced negative Eu anomalies ($Eu/Eu^* = 0.33, 0.39$). The Lynn Lake rhyolite, and other rhyolites in the Northern Belt, have moderate to steep patterns and moderately negative to negligible Eu anomalies.

Recent work in the Superior Province (Campbell et al., 1983; Campbell et al., 1982a,b; Campbell et al., 1980a,b; Thurston, 1981) has demonstrated that REE geochemistry can be used to distinguish felsic volcanic rocks associated with Cu-Zn massive sulphide deposits from those not associated with ore. The work has further demonstrated a genetic link between ore deposits and subvolcanic sills, and the immobility of REE and HFS elements in metamorphosed felsic rocks except in alteration pipes which focussed hydrothermal fluids beneath ore deposits. These authors subdivide Archean felsic volcanic rocks in the Superior Province into three types based on their REE geochemistry (Table 5; see also Fig. 58): Type 1 show a close association with ore deposits, Type 2 are apparently unique to the Archean and are never associated with ore deposits, and Type 3 may be associated with ore deposits, where they are underlain by large synvolcanic sills.

Rhyolites in the Lynn Lake belt can be classified according to the REE characteristics listed in Table 5, as follows: Gemmell Lake (4001-3) and Hughes Lake calc-alkaline rhyolites (42, 45) are Type 1, Snake Lake dacite (132) is Type 2, and Lynn Lake rhyolite (4010-1, 4012-4, 4013), other Northern Belt rhyolites (92, 503-1) and Snake Lake rhyolite (135) are Type 3. In a more comprehensive context, however, there are problems with this simple approach:

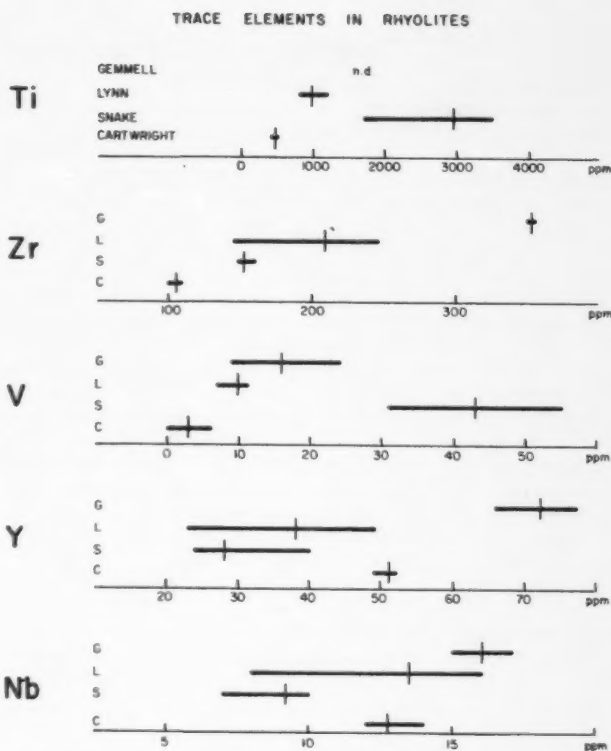


Figure 54: Ti, Zr, V, Y and Nb abundances in the Gemmell, Lynn, Snake and Cartwright Lakes rhyolite bodies. The range of measured concentrations (ppm) are indicated by the bars; the short vertical line is the average concentration. n.d. = not determined.

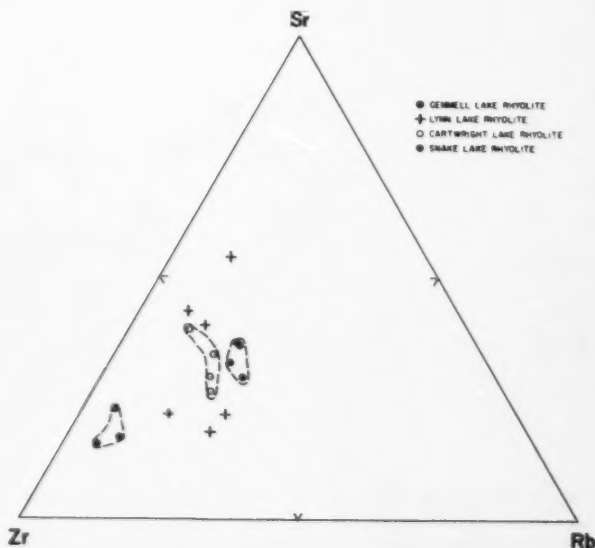


Figure 55: Ternary Zr-Sr-Rb plot, rhyolites.

Table 5:
Classification of Superior Province rhyolites (after Campbell et al., 1983).

Table 5

	TYPE 1	TYPE 2	TYPE 3
Affinity	Tholeiitic	Calc-alkaline	Calc-alkaline
REE Pattern	Flat	Steep	Moderate to shallow
La_N/Yb_N	1 - 4	5 - 40	2.5 - 6
Eu anomaly (Eu/Eu^*)	Pronounced negative (0.25 - 0.90)	Weakly negative to moderately positive (0.85 - 1.6)	Weakly to moderately negative (0.55 - 1.1)
Yb_N	10 - 120	2 - 30	
Incompatible trace element content (HREE, Y, Zr, Hf, U, Th)	High	Low	Moderate
Composition	Rhyolite	Dacite	Rhyodacite, rhyolite
Rock association	Bimodal rhyolite- basalt sequence	Upper parts of basalt-andesite dominated sequences; only minor rhyolite.	
Derivation	Partial melting of associated tholeiitic basalt during intrusion of, and fractional crystallization in, high level magma chambers.	Deep source; garnet and no plagioclase in residue. Minimal fractionation prior to emplacement.	Similar to modern. Shallower source and/or higher degree of partial melting than Type 2. Subsequent fractional crystallization.
Associated synvolcanic sill	Yes	No	Some
Ore association	Close association	Never associated	May be favourable
Examples	Kamiskotia, Kidd Creek, Matagami, Noranda, South Bay	Bowman Subgroup, Kakagi Lake, Shoal Lake	Misema Subgroup, Sturgeon Lake, Wabigoon

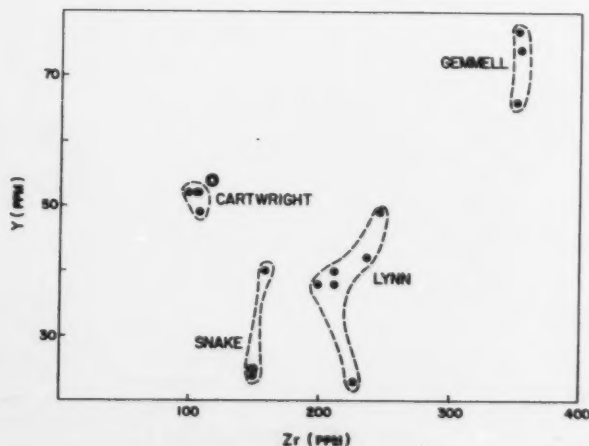


Figure 56:

Y vs. Zr, rhyolites. Each body has a characteristic Zr/Y ratio or range of ratios. The star symbol adjacent to the Cartwright Lake rhyolite field indicates a small rhyolite body east of Hughes Lake (analysis 45). Like the Cartwright Lake body this rhyolite occurs in the Hughes Lake calc-alkaline sequence.

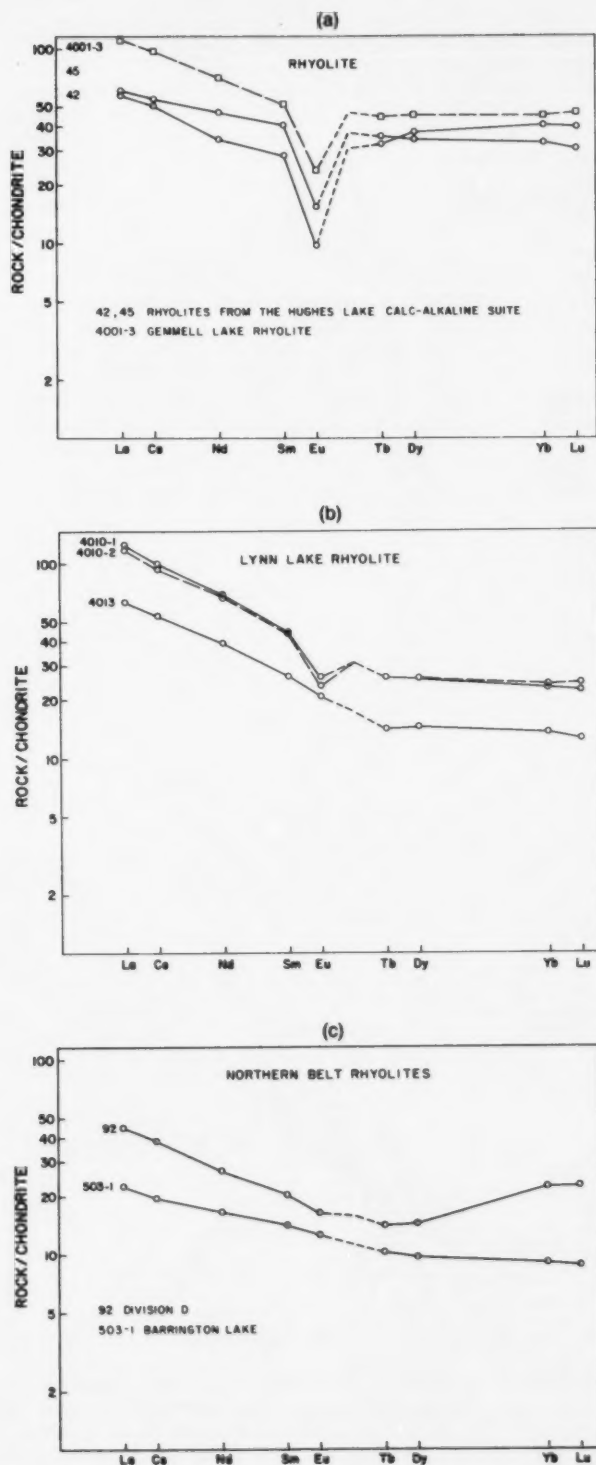


Figure 57: Chondrite normalized REE plots, Wasekwan rhyolites. (a) flat patterns with significant negative Eu anomalies (Hughes Lake calc-alkaline rhyolites, Gemmell Lake rhyolite), (b) Lynn Lake rhyolite complex, (c) Northern Belt rhyolites (Division D and Barrington Lake).

(1) The Hughes Lake "Type 1" rhyolites are not associated with any known Cu-Zn ore deposits nor even significant Cu-Zn showings; further they are calc-alkaline rather than tholeiitic. They are associated with andesites and are not part of a bimodal rhyolite-basalt sequence.

(2) The Snake Lake "Type 2" dacite is stratigraphically associated with the Fox Mine Cu-Zn orebody.

(3) The Lynn Lake "Type 3" rhyolite contains the Nicoba Cu-Zn sulphide deposit (Baldwin, 1983) but is not associated with any known subvolcanic sill.

Data from the Proterozoic Flin Flon belt shows that the rhyolite associated with the Flin Flon Cu-Zn orebody would be classified as Type 1 by its flat REE pattern, but it does not have a Type 1 europium anomaly.

Rhyolites with flat REE patterns and substantial negative Eu anomalies are more fractionated than those with LREE enrichment and small Eu anomalies (Miller and Mittlefehldt, 1982). The most highly fractionated rhyolites in a given suite may have the greatest potential for sulphide association; other factors, however, are probably equally if not more significant in determining whether or not a massive sulphide body will be deposited (and preserved). Such factors include the presence and preservation of basinal environments, the presence of subvolcanic intrusions ("heat engines") which drive hydrothermal convection cells, and the presence of synvolcanic faults and fractures which focus the metal-bearing discharge of hydrothermal convection systems.

Characterization of Archean rhyolites according to REE pattern and ore-association appears to be consistent, at least for the rhyolites studied to date (Campbell et al., 1983). However, the data above indicate that this type of classification cannot be extended, at present, to the Proterozoic metavolcanic belts of Manitoba (Fig. 58).

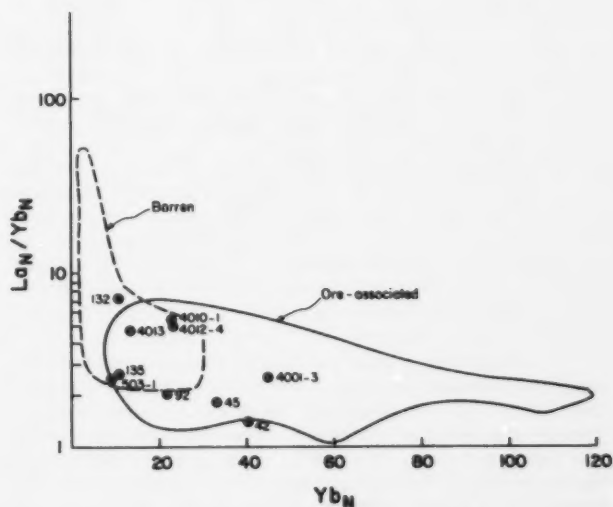


Figure 58:

La_N/Yb_N vs. Yb_N rhyolites. Circled dots would be classified as Type 1 in the classification of Campbell et al. (1983). Fields of Archean Superior Province ore-associated and barren rhyolites from Campbell et al. (1983).

WASEKWAN GROUP Mg-Fe-Ni-Cr RELATIONSHIPS

The mafic components (Mg, Fe, Ni, Cr) of lavas display the greatest and most significant variation in ancient and recent volcanic provinces (Jolly, 1975). The variation can be integrated into a petrogenetic model summarizing the basic processes which produced the major magma series in the Lynn Lake belt.

The MgO-FeO* relations of Wasekwan Group rocks are summarized in Figure 59. The three major chemical series (tholeiitic, primitive calc-alkaline and calc-alkaline) are identified by the shapes of the curves which define the compositional variation within individual lithostratigraphic units. Tholeiitic suites have a high-MgO stem, an "iron enrichment" peak of 10-14 per cent FeO* at MgO contents between 4 and 6 per cent, and steadily declining FeO* through the range between 0 and 4-6 per cent MgO. The primitive calc-alkaline suite displays no iron enrichment whatever, but rather an abrupt linear decrease in MgO with minor decrease in FeO*. The calc-alkaline suite displays a regular, linear decrease in FeO* and MgO through the entire MgO range of the suite.

The three major chemical series are also identified by their Ni and Cr variation (Fig. 59). High MgO members of the tholeiitic series have high Ni and Cr values; these decrease steadily to the "iron enrichment" peak at 4-6 per cent MgO. Ni and Cr are then almost constant through the range between 1 and 4-6 per cent MgO. This variation suggests crystal fractionation of olivine and pyroxene in the more magnesian magmas, severely depleting subsequent liquids in Ni and Cr. The iron enrichment trend is attributed (Osborne, 1962) to absence of Fe-Ti oxide formation until the $f(\text{O}_2)$ of a magma reaches a level sufficient to allow crystallization of magnetite; subsequent precipitation of magnetite yields Fe-depleted differentiates. As was discussed previously, early precipitation of magnetite may have occurred in Northern Belt magmas because the degree of iron enrichment displayed by those lavas is not pronounced. Olivine ceased to be a fractionating phase in later mafic and intermediate Northern Belt magmas because Ni (and Cr) are almost constant through that MgO range.

The primitive calc-alkaline suite is characterized by moderate Ni and very high Cr in the most magnesian members. With decreasing MgO, Cr is substantially depleted and Ni moderately depleted; this variation has been shown to be produced primarily by fractionation of Cr-bearing Ca-pyroxene.

The calc-alkaline series shows only minor depletion in Ni through the MgO range corresponding to basalt through andesite; Cr decreases by a factor of one-half. This suggests that Fe consumption by oxides and Cr-bearing pyroxene prevented Fe enrichment in successive differentiates. Ni and Cr contents in the calc-alkaline suite are equivalent to or higher than those in tholeiites within the same range of MgO. This effectively precludes derivation by fractional crystallization of the calc-alkaline suite from any of the tholeiitic magma series.

The MgO-FeO* relations displayed by the Wasekwan Group are substantially different from those determined for the Archean Abitibi Belt (Jolly, 1975). The earliest lavas in the completely exposed cycle II (Dimroth et al., 1982) of the Abitibi Belt comprise a magnesian series of komatiitic and tholeiitic flows which has no direct counterpart in the Wasekwan Group. Tholeiites occupy the middle stratigraphic level in the Abitibi Belt: relative to Wasekwan tholeiites they are richer in iron, display a much greater degree of iron enrichment (FeO* up to 20 wt. per cent vs. 14 wt. per cent in the Wasekwan Group), and contain, on average, 3 times as much Ni as Wasekwan tholeiites (150 ppm vs. 53 ppm). Calc-alkaline rocks top the stratigraphic sequence in the Abitibi Belt; source magmas of the series are interpreted by Jolly (1975) to lie on the same evolutionary trend as the source magmas of the tholeiitic

and magnesian series. The Wasekwan calc-alkaline series by contrast is sandwiched between tholeiitic basalt below and transitional basalt above, and has a possible primitive precursor with an evolutionary trend distinct from that of the tholeiitic series. Typical Abitibi Belt calc-alkaline andesites are characterized by high Ni (150 ppm) and Cr (70 ppm) whereas Wasekwan calc-alkaline andesites contain much lower Ni (59 ppm) and similar Cr (64 ppm).

Jolly (1980) interprets the chemistry and stratigraphy of the Abitibi lavas to be consistent with two different models. In the first, partial melting in the mantle at 30 kb produces an "ultramafic basalt" liquid which fractionates (at less than 9 kb) to produce the mafic parental liquids of the tholeiitic and calc-alkaline series. Continuous elevation of many batches of these parental liquids, combined with and subvolcanic crystal fractionation, produces the observed range of rock types. In the second model, continuous partial melting at relatively shallow levels (less than 9 kb) and at progressively declining temperatures produces the mafic end members of the magnesian, tholeiitic and calc-alkaline suites in the observed temporal sequence. Continuous elevation of many batches, and subvolcanic crystal fractionation, produces the range of liquids observed in each suite. Fractionation of olivine, clinopyroxene, plagioclase, and Fe-Ti oxides in intermediate members, is considered

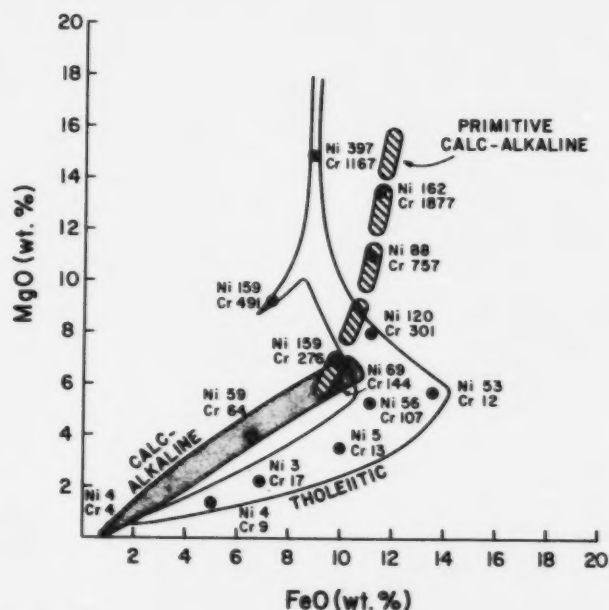


Figure 59:

MgO vs. FeO*, Wasekwan Group. Shaded areas represent most of the chemical variation displayed by individual magmatic suites (Figs. 20, 40, 47, 49 and other suites not shown). Average Ni and Cr were calculated at selected positions within major trends and transferred to this generalized plot. Note that for the tholeiitic group the Ni and Cr for MgO less than 4 per cent are calculated from Northern Belt Division B as this suite contains the most abundant intermediate compositions.

to have produced the trends of extreme Fe enrichment in the tholeiitic series. The calc-alkaline series was produced by simultaneous fractionation of clinopyroxene, plagioclase and magnetite; precipitation of the oxides subdued Fe enrichment.

The chemistry and stratigraphy of the Wasekwan Group reflects a somewhat different melting-differentiation-eruption history. Fractionation of olivine and pyroxene from source magmas containing a lower Ni content than Abitibi source magmas produced the trends to iron enrichment in the tholeiitic suites. The subdued nature of the iron enrichment trends suggests that the magmas had somewhat elevated $P(H_2O)$ and $f(O_2)$ levels which permitted co-precipitation of small amounts of Fe-Ti oxides early in the differentiation sequence; more abundant oxide removal at 4-6 per cent MgO may reflect the subsequent attainment of higher $f(O_2)$ levels by the fractionating magmas.

The "inverted" compositional cycle in the Northern Belt could have been produced by fractional crystallization of an aluminous basalt magma, development of a compositionally zoned magma chamber, and eruption of the contents of the chamber following caldera collapse. Alternatively, it may reflect a progressive increase in partial melting with time, thus concentrating the relatively volatile elements and incompatible trace

elements in the lower part of the sequence and the refractory elements in the upper part of the sequence. Subvolcanic crystal fractionation of clinopyroxene, plagioclase and Fe-Ti oxides produced the range of rock compositions in the sequence.

The independent evolution of separate eruptive centres in the Southern Belt, as evidenced by individual major and trace element trends, indicates that fractionation processes and parent magma compositions varied throughout the volcanic belt. Differentiation must have occurred in separate high-level magma chambers.

Wasekwan primitive calc-alkaline and calc-alkaline series have trace and major element abundances which indicate they were not derived from the magmas which differentiated to produce the various tholeiitic series. They appear to represent separate liquid line(s) of descent characterized by early massive precipitation of clinopyroxene (the primitive, basaltic sequence) and subsequent co-precipitation of oxides and clinopyroxene (the dominantly andesitic sequence). The $P(H_2O)$ and $f(O_2)$ of the magmas must have been sufficiently elevated to induce oxidation of Fe^{2+} but not high enough to stabilize amphibole in place of clinopyroxene. Fe enrichment was suppressed by incorporation of Fe^{3+} in the precipitating phases.

CHEMO-STRATIGRAPHIC SUMMARY

The Lynn Lake belt can be broadly divided into five major chemical groups:

(1) Tholeiitic basalts with low Ni and Cr contents, similar in some respects to modern island arc tholeiites (Cockeram Lake basalt, Tod Lake basalt). The Hughes Lake transitional basalts are, for convenience, included in this group.

(2) Tholeiitic, high-alumina basalts and andesites with very low Ni and Cr contents, again similar in some respects to modern island arc tholeiites (Northern Belt basalts and andesites, Miskwa Lake basalts, Keewatin River basalts). The high-alumina basalts are associated with "normal"-alumina basalts with higher MgO, Ni and Cr.

(3) Porphyritic basalts with primitive calc-alkaline characteristics (Fox Lake basalt, McVeigh Lake basalt).

(4) Calc-alkaline basalt, andesite, dacite and rhyolite (Hughes Lake suite).

(5) Felsic volcanic complexes (Snake Lake dacite, Lynn Lake rhyolite, Keewatin River dacite).

SOUTHERN BELT

Primitive calc-alkaline and quartz-normative tholeiitic basalts form the mafic substrate of the Southern Belt. Each of the Fox, McVeigh and Cockeram Lake bodies probably represents a separate eruptive centre, and interfingering of the Cockeram and McVeigh Lake basalts indicates that the two chemical types were contemporaneous. Chemical variation in both the primitive calc-alkaline suite and the tholeiitic basalts was controlled by fractionation of Ca-pyroxene.

Felsic complexes (Snake Lake dacite, Fraser Lake rhyolite) and a thick calc-alkaline sequence (Hughes Lake suite) overlie the basaltic substrate of the Southern Belt. The contact between the primitive calc-alkaline porphyritic basalts and the felsic rocks varies from conformable (Fox Lake basalt — Snake Lake dacite) to sharp and possibly disconformable (McVeigh Lake basalt — Fraser Lake rhyolite). The Snake Lake dacites may be felsic differentiates of the primitive calc-alkaline basalt suite; major and trace element evidence also suggests that the trend to more siliceous compositions within the Snake Lake felsic suite was produced at least in part by fractionation of pyroxene. The Snake Lake dacites were emplaced contemporaneous with the deposition of the predominantly mafic Fox Mine succession.

The Hughes Lake calc-alkaline suite conformably overlies Cockeram Lake quartz tholeiitic basalt; the contact is lithologically abrupt. Separate segments of the calc-alkaline suite each display trends to more siliceous compositions with time: in the dominantly andesitic Pole Lake segment the stratigraphically highest member is dacitic, and in the Hughes Lake section a thick basalt-basaltic andesite sequence is overlain by andesite and capped by rhyolite. The K_2O and transition element abundances of the andesites are broadly similar to Cenozoic low-K island arc andesites. Stratigraphically separate rhyolite bodies in the suite have identical trace element abundances, which serve to distinguish them from other felsic complexes in the Lynn Lake belt.

Each of the felsic complexes for which adequate chemical data are available (Snake, Gemmell, Lynn and Cartwright Lake bodies) has a unique trace element and REE signature. The trace element and REE data indicate that the complexes were not produced from a single compositionally zoned magma chamber. The unique signature of each rhyolite (or group of rhyolites within a particular magmatic association) probably reflects its evolution in a separate magma chamber, the composition of the parent magma, and the fractionation processes by which it was produced.

Throughout the entire Southern Belt the felsic complexes and the calc-alkaline sequence are overlain by units of basalt which vary widely in form, extent, petrography and chemistry. In the Laurie Lake-Wilmot Lake area the Snake Lake dacites and contemporaneous Fox Mine succession are interpreted to be succeeded by the tholeiitic Tod Lake basalt (in the west) and the Wilmot Lake-Nail Lake volcanics (in the east). The Fraser Lake felsic volcanic body is overlain by mafic rocks which are correlated with part of the Wilmot Lake-Nail Lake succession. At Hughes Lake, the calc-alkaline sequence is overlain by olivine-normative transitional basalt.

The Tod Lake basalt straddles the boundary between the Lynn Lake greenstone belt and the Kisseynew sedimentary gneiss belt; a general trend to lower TiO_2 , lower $FeO^*/(FeO^* + MgO)$ and higher MgO is present from the thick proximal section near Fox Mine to the thin distal section within the gneissic belt. Despite the high MgO, very low TiO_2 character of the distal section there are no clear separations of the suite into komatiitic and tholeiitic members.

The Wilmot Lake volcanics comprise two chemical/geographic groups, one corresponding to the area west of Wilmot Lake and the other corresponding to the area between Franklin Lake and Gemmell Lake. The Wilmot Lake group is tholeiitic in character, with a wide range of FeO^*/MgO and low transition element contents, but it cannot be correlated chemically with any of the better known basalt suites. The Franklin Lake-Gemmell Lake group has the Northern Belt characteristic of associated high-alumina and "normal"-alumina/high-MgO basalts. The high-alumina basalts correspond closely in major element composition to Division B high-alumina basalts but have Division D REE patterns. The "normal"-alumina basalts more closely resemble equivalent Division D basalts.

NORTHERN BELT

The lowermost preserved member in the homoclinal Northern Belt is the large rhyolite complex south of Lynn Lake town (Division A). The chemistry of the mafic to intermediate volcanic portion of the Northern Belt (Divisions B, D and E) is dominated by two major features: the association of high-alumina basalts with less voluminous "normal"-alumina basalts and the apparently abrupt chemical contact between Divisions B and D. Within each of Divisions B and D is a relatively weak tholeiitic trend of iron enrichment in which the "normal"-alumina basalts form the higher MgO ends, and the high-alumina basalts define the portions with steadily decreasing MgO and FeO^* . All of the Division D basalts are chemically less evolved than the earlier Division B basalts, and it is clear that Division D magmas were not generated by fractionation of Division B magmas. The chemo-stratigraphic relations in the 7-8 km thick Northern Belt (rhyolite overlain by evolved basalts and andesites overlain by more primitive basalts) comprise an "inverted" volcanic cycle in which, on a large scale, the contents of MgO, Ni, Cr and V in lavas increase stratigraphically upwards whereas SiO_2 , K_2O , TiO_2 , P_2O_5 , Zr, Sr, Rb, Ba and Y decrease upwards.

Direct stratigraphic correlation of the Northern Belt with any of the rock units in the Southern Belt is precluded by the physical separation of the belts by a chain of tonalite plutons. Chemical correlation of the Gemmell Lake-Franklin Lake portion of the Southern Belt (above) with the Northern Belt is possible, although two differences reduce the confidence of the correlation: (1) high-alumina basalts with both Division B and D characteristics are associated with Division D-type "normal"-alumina/high MgO basalts, and (2) the "normal"-alumina/high MgO basalts in the Gemmell Lake-Franklin Lake portion are not exactly

equivalent to Division D "normal"-alumina basalts. However, it seems certain that at least part of the Wilmot Lake-Nail Lake succession comprises Northern Belt-type material and thus Northern Belt-type volcanic rocks form the upper portion of the Wasekwan Group in the Lynn Lake belt.

The simplified chemo-stratigraphic relationships in the Lynn Lake belt are displayed in Figure 60. Problems in correlation between the Southern and Northern Belts (discussed above) make the stratigraphic position of the Northern Belt high-alumina tholeiites somewhat uncertain. West of Franklin Lake the basaltic sequence containing high-alumina members directly overlies tholeiitic and primitive calc-alkaline basalts; evidently paleogeography and the distribution of eruptive centres had a significant effect on local stratigraphy.

The fundamental separation of the Lynn Lake volcanic belt into a northern, high-alumina tholeiite belt, a southern, tholeiite plus calc-alkaline belt, and a discontinuous belt of high-alumina and "normal"-alumina basalts south of Johnson shear zone may reflect a large-scale primary separation of mainly contemporaneous magmatic types, subse-

quently accentuated by structural adjustments. Chemical zonation parallel to the axes of volcanic belts, resulting in compositional variation across the belts, is a feature of Cenozoic island arcs in an advanced stage of evolution (Jakes and White, 1972; Colley and Warden, 1974; Mitchell and Reading, 1971). In Cenozoic arcs the tholeiitic rocks occur on the oceanic or trench side, followed inland by high-alumina basalts (Kuno, 1966; Jakes and White, 1971, 1972). There is also a variation in composition with time (Jakes and White, 1972; Miyashiro, 1974); early stages of arc development are dominated by low-K "arc tholeiites" with Fe enrichment fractionation trends. Over time the magmas become enriched in incompatible elements and show less iron enrichment, so that calc-alkaline lavas are erupted. Very enriched shoshonitic lavas dominate in the advanced stages of arc development, when the crust beneath arcs approaches continental thickness. The stratigraphic and geographic chemical variation in the Lynn Lake belt is broadly comparable to the chemical variation in evolved and tectonically complex Cenozoic island arcs.

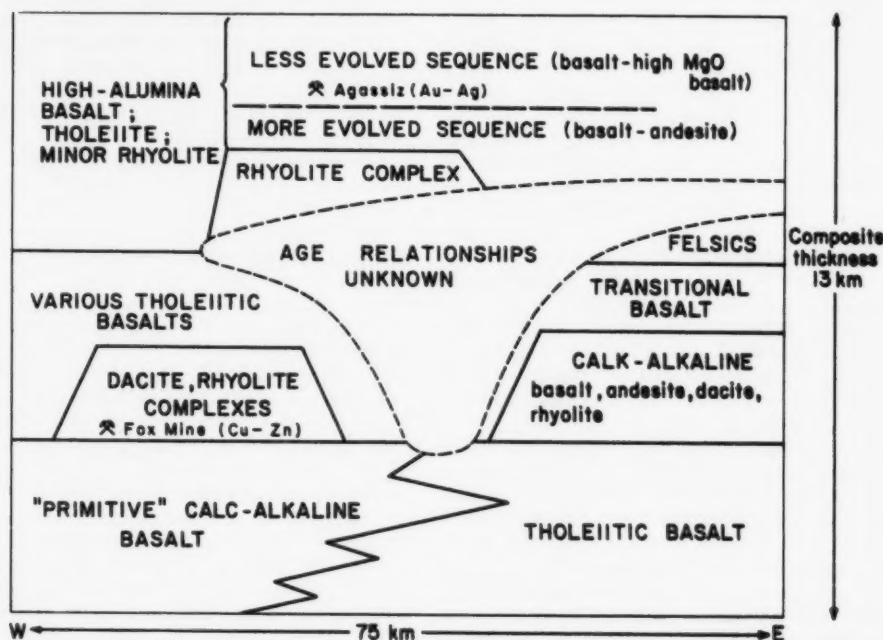


Figure 60: Simplified chemo-stratigraphic relationships for volcanic rocks in the Lynn Lake belt.

ECONOMIC CONSIDERATIONS

The metallogeny of the Lynn Lake belt should be considered with reference to the overall chemo-stratigraphy of the belt as shown in Figure 60. Most of the geochemical information outlining the magmatic diversity and evolution of the Wasekwan Group comes from thick piles of generally unmineralized mafic flows. Stratabound volcanogenic mineralization in the Lynn Lake area, however, occurs predominantly in felsic fine grained sediments and volcanic fragmental rocks (Ferreira and Baldwin, 1984; see also Fedikow and Gale, 1982; Gale, 1983; Gale and Koo, 1977; Koo, 1976). Consequently the stratigraphic positions of the mineralized volcanoclastic units must be determined relative to these prominent mafic units and thereby integrated into the chemo-stratigraphy. The mineral data base comprising deposit descriptions and local stratigraphic setting (Ferreira and Baldwin, 1984) can be used in conjunction with more regional mapping (Gilbert et al., 1980) to provide such an overview.

On a large scale the distribution of mineral occurrences in the Lynn Lake area coincides with the division of the greenstone belt into Northern and Southern Belts. Stratabound Cu-Zn sulphide and Au occurrences are much more common in the Northern Belt than in the portion of the Southern Belt between Gemmell Lake and Hughes Lake. The implication is that the upper part of the Wasekwan Group, as represented by Northern Belt high-alumina and "normal"-alumina tholeiites (Fig. 60), is geologically more favourable than the lower part of the Wasekwan for stratabound mineral deposits. Possible factors bearing on this preferential distribution of volcanogenic mineral deposits include the geochemistry and origin of Northern Belt volcanic rocks, the nature of the volcanism that produced them, and the types of depositional environments that were present during volcanism.

The Southern Belt Hughes Lake calc-alkaline suite (Fig. 60) is striking in that no known stratabound sulphide deposits occur in this thick (2500 m +) sequence of basalt, andesite and rhyolite. Archean calc-alkaline units commonly do host volcanogenic Cu-Zn massive sulphide deposits (e.g. Gélinas et al., 1982).

At present only two stratabound deposits in the Lynn Lake area are economically significant; these are the Fox Mine Cu-Zn massive sulphide deposit and the Agassiz Au-Ag deposit. The Fox Mine deposit occurs in a fault-bounded slice of felsic volcanic rocks (Olson, 1984) interpreted as stratigraphically equivalent to the Snake Lake dacite (Gilbert et al., 1980). The Snake Lake dacite overlies the Fox Lake primitive calc-alkaline basalt and is one of several felsic to intermediate complexes which occur upon the basaltic "platform" of the Southern Belt (Fig. 60). The Agassiz deposit (Fedikow and Gale, 1982; Fedikow, 1983; Fedikow et al., 1984) is stratigraphically approximately midway through Division D in the Northern Belt (Fig. 60). It is hosted by a 15

m thick unit comprising mafic tuffaceous, clastic and chemically precipitated sedimentary rocks. The Au-bearing unit is underlain by an altered, high-MgO member of the Division D suite and is overlain by altered basalt. A persistent gradiometer anomaly extending from the Agassiz deposit 40 km northeast to the vicinity of Farley Lake suggests that the stratigraphic sequence which hosts the mineralization has a regional extent in the Northern Belt. This stratigraphic package represents a major hiatus in Northern Belt volcanic activity, during which exhalative processes resulted in the deposition of oxide facies iron formation, magnetiferous chert, manganiferous carbonate, and massive to disseminated, in part Au-bearing, sulphides.

Whole-rock geochemistry of relatively unaltered volcanic rocks, as described in this report, can be used directly as an aid to exploration. This type of investigation is distinct from multi-sample litho-geochemical exploration techniques which are used to locate and define areas that are characterized by anomalous abundances of ore and ore-associated elements. It has been stressed throughout this report that most of the mafic and felsic volcanic units have unique geochemical "fingerprints" defined by least mobile major, trace and rare earth element concentrations. These "fingerprints" may assist in the definition and extension of volcanic stratigraphy, and are thus potentially useful in mineral exploration to delineate favourable volcanic or intercalated volcanoclastic formations. For example, the trace element "fingerprint" of the Snake Lake dacite (which hosts Fox Mine) is distinct from other felsic volcanic rocks in the belt (Fig. 54) and could be used to identify this particular unit in poorly exposed portions of the southwestern Lynn Lake belt.

Geochemical exploration techniques developed for use in one part of the Shield are not necessarily applicable elsewhere. For example, it was shown above that the three-fold subdivision of Archean rhyolites into ore-associated, possibly-associated and barren types based on REE abundance does not hold for Proterozoic Wasekwan Group rhyolites. Limited data from the Proterozoic Amisk Group (Flin Flon metavolcanic belt) similarly suggest that Proterozoic rhyolite types cannot be classified in the same manner as Archean rhyolites.

The geochemical characteristics of Wasekwan Group volcanic rocks are similar to those in Cenozoic island arcs (see chapter following). Base metal deposits in ensimatic, dominantly mafic island arc magmatic sequences are characteristically pyritic, Cu- and Zn-bearing types with negligible Pb contents (Swinden and Thorpe, 1984). Mineral deposits in the Lynn Lake belt, including Fox Mine, are Cu-Zn dominated (Ferreira and Baldwin, 1984; Gale and Koo, 1977), consistent with an arc environment.

TECTONIC SETTING OF THE WASEKWAN GROUP

INTRODUCTION

The chemical characteristics of magmas emplaced in modern tectonic regimes are determined from relatively fresh Cenozoic volcanic rocks. Comparison of the compositions of variably altered, metamorphosed Precambrian volcanic rocks to modern volcanic suites presents two major problems: (1) Do the present compositions of the Precambrian rocks adequately represent primary compositions? (2) Are the tectonic environments and source areas of Precambrian magmas similar to those in the Phanerozoic?

As was discussed previously the multi-stage alteration history of most Precambrian volcanic rocks has significantly affected the relative distribution and absolute concentrations of most major and trace elements. Consequently the original compositions of the metavolcanic rocks can be estimated only within broad limits. The abundances of the least mobile elements (Ti, P, Zr, Y, Ni, Cr and REE in this study) are considered to be the most representative of primary values.

The Proterozoic (ca. 1.9 Ga) Lynn Lake belt is important because of its potential for investigating and understanding an intermediate stage in the evolution of tectonic regimes, between those which produced Archean metavolcanic belts (ca. 3.8 to 2.5 Ga) and those responsible for Cenozoic volcanic terranes. For example, the tectonic environments in which Proterozoic volcanic rocks were emplaced may have evolved from those that existed in the Archean, through the combined effects of Archean cratonization and lower heat flows in the Proterozoic. Similarly, crustal evolution since the early Proterozoic may have resulted in a different set of tectonic environments in the Cenozoic relative to the Proterozoic.

Moore (1977) has noted that Proterozoic volcanism in Canada has received much less attention than Archean volcanism, despite the crucial importance of this time period in any model of long-term crust-mantle evolution or of global tectonics. Recent work in the Canadian Proterozoic has concentrated mainly on the Circum-Superior Belt (Baragar and Scoates, 1981; Francis et al., 1983) and the Wopmay Orogen (e.g. Hoffman, 1980). Many Proterozoic volcanic suites are considered to have been developed in response to plate tectonics and are subduction-related (e.g. Moore, 1977; Stauffer et al., 1975; Hoffman and McGlynn, 1977). The major and trace element geochemistry of at least some Proterozoic volcanic belts, however, resemble their Archean equivalents more than they do modern volcanics from island arc environments (Condie and Moore, 1977). The early Proterozoic Wasekwan Group volcanic rocks are compared in the following sections to both Archean and Cenozoic volcanic terranes, with a view to (1) establishing the probable tectonic environment in which the Lynn Lake belt developed and (2) providing further documentation of Proterozoic volcanic compositional trends, and implications for the geochemical evolution of the mantle.

COMPARISON WITH ARCHEAN GREENSTONE BELTS

Obvious lithologic similarities exist between rocks in the Lynn Lake belt and those in Archean greenstone belts: both comprise a stratified sequence of flows, breccias, tuffs and sediments, deposited predominantly in a subaqueous environment, which were subsequently folded, metamorphosed to greenschist or amphibolite facies, and intruded by granitoid plutons. However, in detail there are major differences between the Proterozoic Lynn Lake Belt and Archean volcanic sequences:

(1) The total thickness of the volcanic sequence at any given locality in the Lynn Lake Belt is small compared to the enormous thickness of some Archean volcanic piles. A maximum of 8700 m of volcanic strata occur in the Northern Belt although minor folds or faults could reduce this apparent thickness; in the Southern Belt continuous sections of more than 5000 m are absent. By contrast Archean sequences of 7-30 km (e.g., Dimroth et al., 1982; Goodwin and Smith, 1980; compilation by Glikson, 1976) have been recorded.

(2) Wasekwan Group stratigraphy is dominated by relatively small, overlapping volcanic centres and associated epiclastic aprons; the compositional cyclicity displayed in some Archean greenstone belts (Thurston and Fryer, 1983; Hubregtse, 1978; Thurston, 1980; Ayres, 1977) is absent.

(3) In the Lynn Lake Belt a calc-alkaline sequence is bracketed by tholeiitic basalts below and transitional basalts above; in Archean belts calc-alkaline rocks commonly top the volcanic succession (e.g. Jolly, 1975).

(4) High-alumina basalts are volumetrically important in the Lynn Lake Belt whereas they are rare in the Archean (Gunn, 1976; Hawkesworth and O'Nions, 1977).

(5) High-MgO basalts in the Lynn Lake belt are probably members of the tholeiitic suites and do not occur at the base of the volcanic succession. Ultramafic to mafic lavas (variously described as ultramafic volcanics, komatiites, magnesian series) comprise the basal or lower portions of some Archean greenstone belts (e.g. Viljoen and Viljoen, 1969; Hawkesworth and O'Nions, 1977; Jolly, 1975, 1980; Dimroth et al., 1982).

(6) Tholeiitic suites in the Wasekwan Group display limited iron enrichment relative to the marked iron enrichment in some Archean tholeiitic sections (e.g. Jolly, 1975, 1980).

(7) Wasekwan Group tholeiites contain, on average, more Sr and less Ba than average Archean tholeiites (Table 6). K_2O contents are approximately the same (about 0.3 per cent). Rb/Sr ratios average about 0.04 in Archean basalts but are only 0.02 in the Wasekwan Group.

(8) The Ni and Cr contents of all Wasekwan Group rock types (tholeiitic and calc-alkaline, basalt through rhyolite) are one-half to one-quarter those in equivalent Archean volcanic rocks (Table 6). The distribution of Ni values for all Wasekwan Group basalts (Fig. 61) clearly shows that this Proterozoic belt is characterized by significantly lower Ni than Archean belts.

(9) Archean tholeiites typically have flat to slightly LREE-depleted patterns (La_N/Yb_N approximately 0.7 to 1.8) with Yb_N ranging from 5 to 36 (Sun and Nesbitt, 1978; Hawkesworth and O'Nions, 1977; Smith, 1980; Ludden et al., 1982). Fractionated, Fe-rich Archean tholeiites display the upper range of La_N/Yb_N ratios and Yb contents. Wasekwan tholeiites, from the entire range of Northern and Southern belt types, typically have flat to moderately LREE-enriched patterns ($La_N/Yb_N = 0.9$ to 3.3) with Yb_N 5 to 19 times chondrite. The Cockeram Lake quartz tholeiite, as an example of a single suite, has a La_N/Yb_N ratio of about 2 and Yb_N of 19 times chondrite. Thus the Wasekwan tholeiites correspond generally in REE concentration with Archean Fe-tholeiites, but, significantly, Wasekwan basalts do not display the high Fe contents of evolved Archean tholeiites.

(10) Archean calc-alkaline volcanic rocks apparently comprise two distinct types: Type 1 displays marked HREE-depletion (Yb_N about 1 to 7) with LREE contents similar to evolved tholeiites, whereas Type 2 displays LREE/HREE fractionation without HREE depletion — Yb_N is 7 to 15. Examples of Type 1 occur in Rhodesia (Hawkesworth and O'Nions, 1977) and Finland (Jahn et al., 1980) and examples of Type

Table 6:
Average contents of selected elements in tholeiitic basalt.

	K ₂ O	TiO ₂	Rb	Sr	Ba	Ni	Zr
Wasekwan Group ¹	0.30	0.94	4	233	69	53	74
Island Arc ²	0.44	0.80	5	200	75	30	70
Archean (Superior Province) ³	0.33	1.16	6	149	99	162	108

¹ includes all tholeiitic basalts, excluding samples displaying obvious alkali metasomatism (n = 73 for K₂O; 87 for TiO₂, Ni, Cr; 22 for Rb, Sr, Ba; 28 for Zr).

² Jakes and White, 1972

³ Goodwin, 1977

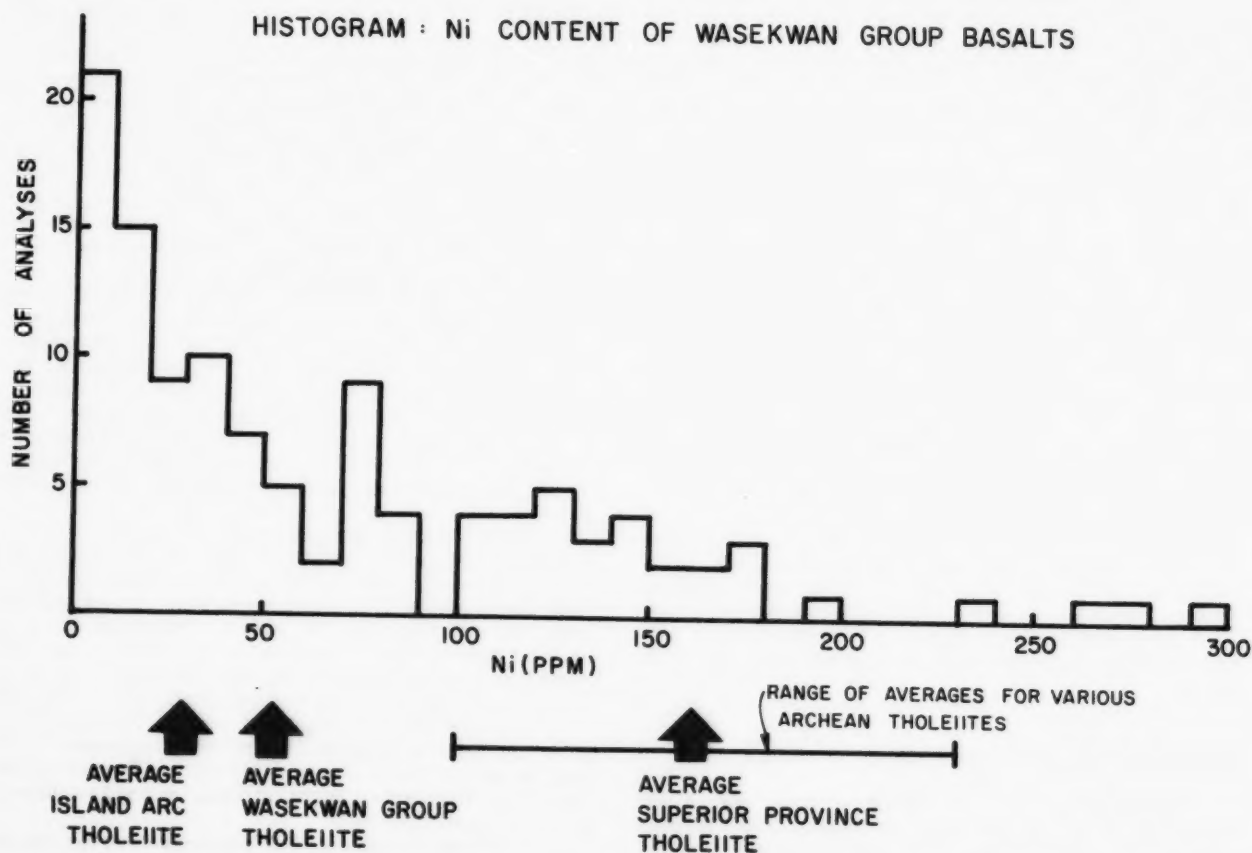


Figure 61: Histogram of Ni content in Wasekwan Group basalts (n = 114). Average Ni contents in Cenozoic arcs (Jakes and White, 1972) and Archean greenstone belts (references in Table A4) for comparison.

2 occur in the Abitibi Belt (Smith, 1980; Ludden et al., 1982; Thurston et al., 1984) in the Marda complex, Yilgarn Block, Australia (Taylor and Hallberg, 1977), and in the Pilbara Block, Australia (Barley et al., 1984). Wasekwan calc-alkaline andesites are similar to Archean Type 2, with Yb_N 10.6 to 12.5 and La_N/Yb_N ratios ranging from 3.7 to 6.0. There are no Wasekwan counterparts to Archean Type 1, HREE-depleted volcanic rocks.

ARCHEAN TECTONIC ENVIRONMENTS

The tectonic environment of deposition of Archean greenstone belt volcanic rocks remains a subject of considerable speculation. A variety of models have been proposed; the following constitute a historical sampling and not an exhaustive review. Some authors (for example Jahn et al., 1974; Brooks and Hart, 1974) have suggested that Archean volcanic rocks were deposited in ancient island arc systems, above subduction zones. Arth and Hanson (1975) found the arc model only partly acceptable and concluded that no Cenozoic terrain is directly comparable in detail to the Archean rocks in northeastern Minnesota. Condie (1976) concluded that Archean volcanics were deposited in two tectonic settings, one broadly similar to modern arc associations evolving at convergent plate boundaries on or near continental crust and the other similar to either modern oceanic crust above convergent plate boundaries or a youthful arc system. Tarney et al. (1976) suggest that all rock types found in Archean greenstone belts, and their distinctive geochemistries, are found in Phanerozoic marginal basins. Hawkesworth and O'Nions (1977) note the distinctive trace element geochemistry of Archean volcanics (particularly the high Ni and low Yb contents of the calc-alkaline members) and conclude that no direct comparison can be made with modern island arc associations. They suggest that greenstone belts developed in a rifting environment, in which a high degree of partial melting of mantle material gave rise to the ultramafic volcanics; fractionation of plagioclase, olivine and pyroxene produced the Fe enrichment trend of the tholeiitic lavas, and fractionation of Fe-rich garnet produced the calc-alkaline volcanics with their distinctive trace element and REE geochemistry. Goodwin and Smith (1980) consider that zones of crustal extension were the sites of major tholeiitic and some komatiitic volcanism that resulted from high degrees of mantle partial melting. Sagging of a critical thickness of these lavas, and interaction of the lower part of the pile with the underlying mantle, resulted in a geochemically modified source capable of yielding the calc-alkaline magmas. Thurston et al. (in press) note the bimodal basalt-rhyolite nature of Archean volcanism and conclude that the large volumes of rhyolite produced by Archean island volcanoes are not analogous to any modern volcanic system. They suggest that the closest modern tectonic analogue is continental rift zones of the basin-and-range type; however, unlike modern continental rift zones, Archean rifting resulted in submergence of the crust and development of oceanic volcanoes on rifted sial.

IMPLICATIONS FOR THE GEOCHEMICAL EVOLUTION OF THE MANTLE

There is at present no general agreement on the tectonic environment in which Archean greenstone belts were developed, and most of the recent models have no direct counterpart in the Phanerozoic. Many authors agree that Archean volcanic sequences commonly comprise a lower tholeiitic section (and in some belts a basal komatiitic section [Jolly, 1975; Bickle et al., 1975; Dimroth et al., 1982]) overlain by calc-alkaline rocks, but most point out that major differences (especially in trace element and REE abundances) exist between Archean volcanics and their Phanerozoic counterparts. These differences have been taken by some authors (e.g. Condie, 1976) to indicate that the Archean mantle became depleted in certain elements with time, whereas others (e.g. Hawkesworth and O'Nions, 1977) suggest that the chemistry of the Ar-

chean mantle was essentially the same as it is today, and that the differences in trace and major element chemistry of the derived volcanic rocks simply reflects a hotter Archean mantle. Recent advances in Nd-Sm systematics, however, have shown that the upper portion of the mantle has become depleted in large ion lithophile (LIL) elements with time (O'Nions et al., 1980), and Sun (1980) provides evidence of mantle depletion in Rb, Th, U and LREE since the Archean. Gill (1979) shows that the Archean mantle must have possessed higher concentrations of Ni than the modern mantle.

The Wasekwan Group provides some evidence for the geochemical evolution of the mantle. The geochemical diversity displayed by Wasekwan Group volcanic rocks is a product of high-level fractionation of compositionally distinct batches of primitive magmas. The diversity within the Wasekwan Group however is overshadowed by the differences between it and volcanic rocks in Archean greenstone belts. The lower Rb/Sr ratio, Ni, Fe and Zr, the higher REE, and the absence of Mg-basalts in the Wasekwan Group clearly indicate that these Proterozoic rocks are not direct counterparts of Archean greenstone belts. Evidence summarized in the succeeding section strongly suggests that close similarities exist between the Wasekwan Group and Cenozoic island arcs. Although there is at present no consensus on the tectonic environment(s) in which Archean volcanic rocks were emplaced, they are unlikely to have closely resembled Cenozoic arcs. The lithologic, stratigraphic and geochemical parameters which serve to distinguish the Wasekwan Group from Archean volcanic rocks reflect two significant points: (1) the volcanic rocks were emplaced in differing tectonic environments, and (2) the mantle source of Wasekwan Group magmas was geochemically more evolved than Archean mantle.

The geochemical evolution of the mantle is demonstrated by a number of elements but for the purposes of this report one element deserves special emphasis. It has long been recognized that the content of Ni (as well as, to a lesser extent, V, Cr and Co) in Archean low-K tholeiites is significantly greater than any modern low-K tholeiite (Glikson, 1971; Gill and Bridgwater, 1976; Nesbitt and Sun, 1976; Gill, 1979). When referred to a common Mg-number (Fig. 62) the Ni distribution in MORB and Archean tholeiites differs by a factor of 2 to 3 times; similarly Archean tholeiites clearly do not share the Ni-poor nature of island arc

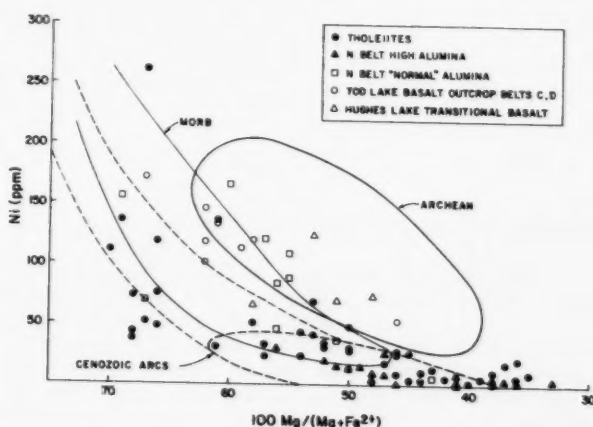


Figure 62:

Ni vs. $100 \text{ Mg}/(\text{Mg} + \text{Fe}^{2+})$, Wasekwan Group basalts (excluding "primitive" calc-alkaline and calc-alkaline basalts). Archean, MORB and Cenozoic arc fields are from Gill (1979). The Cenozoic arc field has been extended (light dashed lines) from that of Gill (1979; heavy dashed lines) to accommodate data from the New Hebrides (Gorton, 1977).

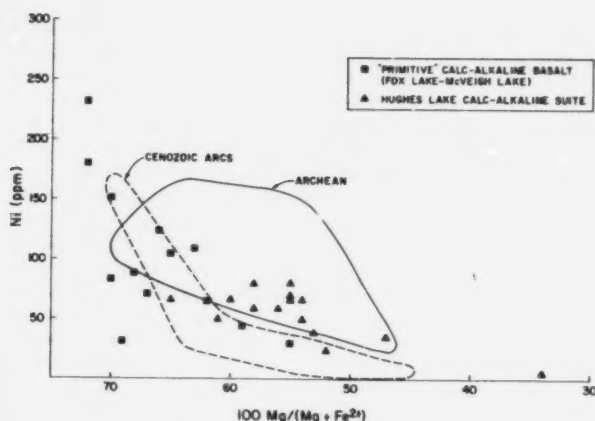


Figure 63: Ni vs. $100 \text{ Mg}/(\text{Mg} + \text{Fe}^{2+})$, Wasekwan Group "primitive" calc-alkaline basalt and calc-alkaline basalts and andesites. Cenozoic arc data from Meijer and Dixon (1981), Gorton (1977). Archean data from Pyke (1982), Hawkesworth and O'Nions (1977).

tholeiites (Gill, 1979). A similar relationship holds for calc-alkaline basalts and andesites: Archean calc-alkaline rocks contain much more Ni than intermediate to mafic lavas in Cenozoic arcs (Fig. 63). The Ni distribution in Archean tholeiites has been interpreted in terms of (1) a higher temperature of melting in the Archean, which lowered the K_D value for the transition metals (Nesbitt and Sun, 1976) or (2) a higher Ni concentration in the Archean mantle than the source regions of all modern low-K tholeiites (e.g. Glikson, 1971; Condie, 1976; Gill, 1979). An Archean mantle characterized by high Ni is preferred due to heat flow considerations (Gill, 1979).

Wasekwan Group tholeiites contain much less Ni than their Archean counterparts (Fig. 62) and Wasekwan calc-alkaline rocks are intermediate between Cenozoic and Archean (Fig. 63), particularly in the common compositional range expressed by Mg numbers 40 to 55. The majority of Wasekwan tholeiites fall well within the ranges established by modern low-K tholeiites. Clearly the source region for Wasekwan tholeiites and calc-alkaline magmas (Proterozoic upper mantle; see below) was similar in Ni concentration to modern upper mantle. By the earliest Proterozoic, evolution of the mantle with respect to Ni abundance, and probably also the abundances of V, Cr and Co, had apparently progressed to compositions approaching modern mantle.

COMPARISON WITH CENOZOIC ISLAND ARCS

The Wasekwan Group can be placed in a known (mapped) geological context which in part reflects its original tectonic environment. The portion of the Lynn Lake metavolcanic belt under consideration in this report is the central sector of the La Ronge-Lynn Lake magmatic belt, with a lateral extent of at least 500 km. The widest part of the belt is about 60 km, although about 75 per cent of this comprises post-Wasekwan tonalite plutons. The Wasekwan Group consists overwhelmingly of volcanic and volcanoclastic rocks deposited in a subaqueous environment (Gilbert et al., 1980). The volcanic rocks are interpreted to have originally formed overlapping volcanic constructs, many of which are flanked by aprons of volcanoclastic sedimentary rocks and tuff. Locally there is evidence that portions of the volcanic edifices emerged above sea level to form ephemeral volcanic islands which subsequently sank below sea level probably due to the combined effects of subaerial erosion and isostatic downwarp. Migmatized metagreywacke turbidites flank

the Lynn Lake metavolcanic belt to the north and south; the metasedimentary rocks interdigitate with the metavolcanic rocks, suggesting that they were deposited at least in part contemporaneously with the Wasekwan Group (Gilbert et al., 1980). The basement on which the Wasekwan Group and flanking greywacke turbidites were deposited has not been identified. In the simplest paleogeographic terms, then, the Wasekwan Group forms part of what originally was a major chain of submarine to subaerial volcanoes in an oceanic setting.

Most of the similarities and differences between Wasekwan Group rocks and volcanic rocks in Cenozoic island arcs have been previously discussed and are briefly summarized below:

(1) The range of rock types present in evolved Cenozoic island arcs (tholeiites, high-alumina basalts, calc-alkaline rocks) are present in the Lynn Lake belt in the approximate stratigraphic sequence (Fig. 60) displayed by island arcs.

(2) Wasekwan tholeiites and high-alumina tholeiites have Ni and Cr contents similar to arc tholeiites and much lower than ocean ridge or inter-arc basalts (Table A5, Appendix). The average Wasekwan tholeiite has a Ni content (53 ppm) intermediate between that of Archean belts (150 ppm) and Cenozoic arcs (30 ppm) (Fig. 61, Tables 6 and A4, A5). The Ni distribution for all Wasekwan basalts (Fig. 61) is very similar to that for island arcs.

(3) Average Rb, Sr and Ba contents in Wasekwan tholeiite are similar to those in island arc tholeiitic basalt (Table 6) and differ significantly from ocean ridge, inter-arc, and marginal basin basalts (Table A5, Appendix). Rb/Sr ratios in the Wasekwan Group (average 0.02) are identical to the average Rb/Sr in island arc tholeiite (Sun, 1980).

(4) Wasekwan calc-alkaline andesites correspond to island arc calc-alkaline andesites in their content of Sr, Ba and TiO_2 and Y (Tables 4 and A5) but Wasekwan andesites have significantly lower K and Rb (possibly a result of sea-floor alteration; note also that the average K_2O listed for arc calc-alkaline andesite by Gunn et al. (1974) is substantially lower than that listed by Jakes and White (1971) (Table 4) and is much closer to the average Wasekwan andesite).

(5) Ni and Cr contents in Wasekwan calc-alkaline andesites are intermediate between those in Archean andesites and those in Cenozoic arc andesites, but are considerably closer to the average Cenozoic arc andesite (Table 4).

(6) Calc-alkaline rocks in Cenozoic intra-oceanic island arcs commonly display mildly enriched LREE patterns ($\text{La}_N/\text{Yb}_N = 1.5$ to 2.5) with Yb_N 7 to 16 times chondrite (e.g. Meijer and Reagan, 1981; Dixon and Stern, 1983; Arth, 1981) although some arcs display considerably stronger LREE enrichment (La_N/Yb_N to about 6; Gorton, 1977). Continental margin calc-alkaline rocks are characterized by marked LREE enrichment (e.g., La_N/Yb_N averaging 11.5 in the Central Andes, Dostal et al., 1977). Wasekwan Group calc-alkaline andesites, with $\text{La}_N/\text{Yb}_N = 3.7$ to 6.0 and $\text{Yb}_N = 10.6$ to 12.5 , are similar to the more strongly fractionated arc lavas.

HFS-REE-LIL RELATIONSHIPS: WERE WASEKWAN MAGMAS GENERATED IN A SUBDUCTION ENVIRONMENT?

It has been suggested (Wood et al., 1979; Tarney et al., 1981; Weaver et al., 1982) that the trace element compositions of basalts generated at mid-ocean ridges and island arcs reflect differences in the melting processes in these two environments. Briefly, the argument is as follows (Weaver et al., 1982): partial melting under high $\text{P}(\text{H}_2\text{O})$ conditions in subduction zones appears to stabilize, in the residuum, minerals such as sphene, ilmenite or rutile which have a strong control over the abundances of HFS elements (Ti, Zr, Hf, Nb, Ta). This results in partial melts displaying a depletion of these elements relative to the REE. Anhydrous melting processes at mid-ocean ridges, on the other hand, produce no fractionation between HFS and REE. The average island arc tholeiite is strongly enriched in LIL elements (Ba, Rb, Th, K, Sr) relative to the HFS and REE: this common feature of subduction related

magmas (Saunders et al., 1980; Tarney et al., 1981) is attributed to transport of LIL elements from the subducting slab during dehydration (Saunders et al., 1980).

Wasekwan Group basalts representing a spectrum of compositional types all display strong "decoupling" of HFS and REE, with depletion of the HFS elements relative to REE (Fig. 64). According to the melting model outlined above, this constitutes strong evidence that these basalts were generated in a subduction or subduction-like environment. It is entirely consistent with Mg-Fe-Ni-Cr relationships which also suggest elevated $P(H_2O)$ in Wasekwan magmas. Pertinent features for the various basalt types are as follows:

(1) The Cockerm Lake quartz tholeiite displays strong depletion of all HFS elements relative to REE. Of the LIL elements, only Rb and Ba are enriched relative to the REE trend, whereas Sr is depleted. The entire trace element pattern (Fig. 64a) is very similar to an "average"

island arc tholeiite pattern but displaced to higher absolute abundances of all elements (except K and Sr). This displacement is probably a result of crystal fractionation, as discussed previously, and presence of clinopyroxene in the residuum of source partial melting. The erratic behaviour of the LIL elements may reflect sea-floor or metamorphic alteration and redistribution of these elements.

(2) Tholeiites from Division D in the Northern Belt (sample 89, "normal"-alumina and sample 86, high alumina) are strongly depleted in Hf, Zr and Ti relative to REE, and are not enriched, or only weakly enriched in LIL relative to the REE trend. The patterns are very similar in absolute trace element abundance except for higher Sr, K and Ba in the high- Al_2O_3 basalt, reflecting an accumulation of plagioclase in sample 86 (note also that sample 89 has no Eu anomaly (Fig. 23b) whereas sample 86 does have a positive Eu anomaly (Fig. 23a), consistent with accumulation of plagioclase). The close similarity in patterns

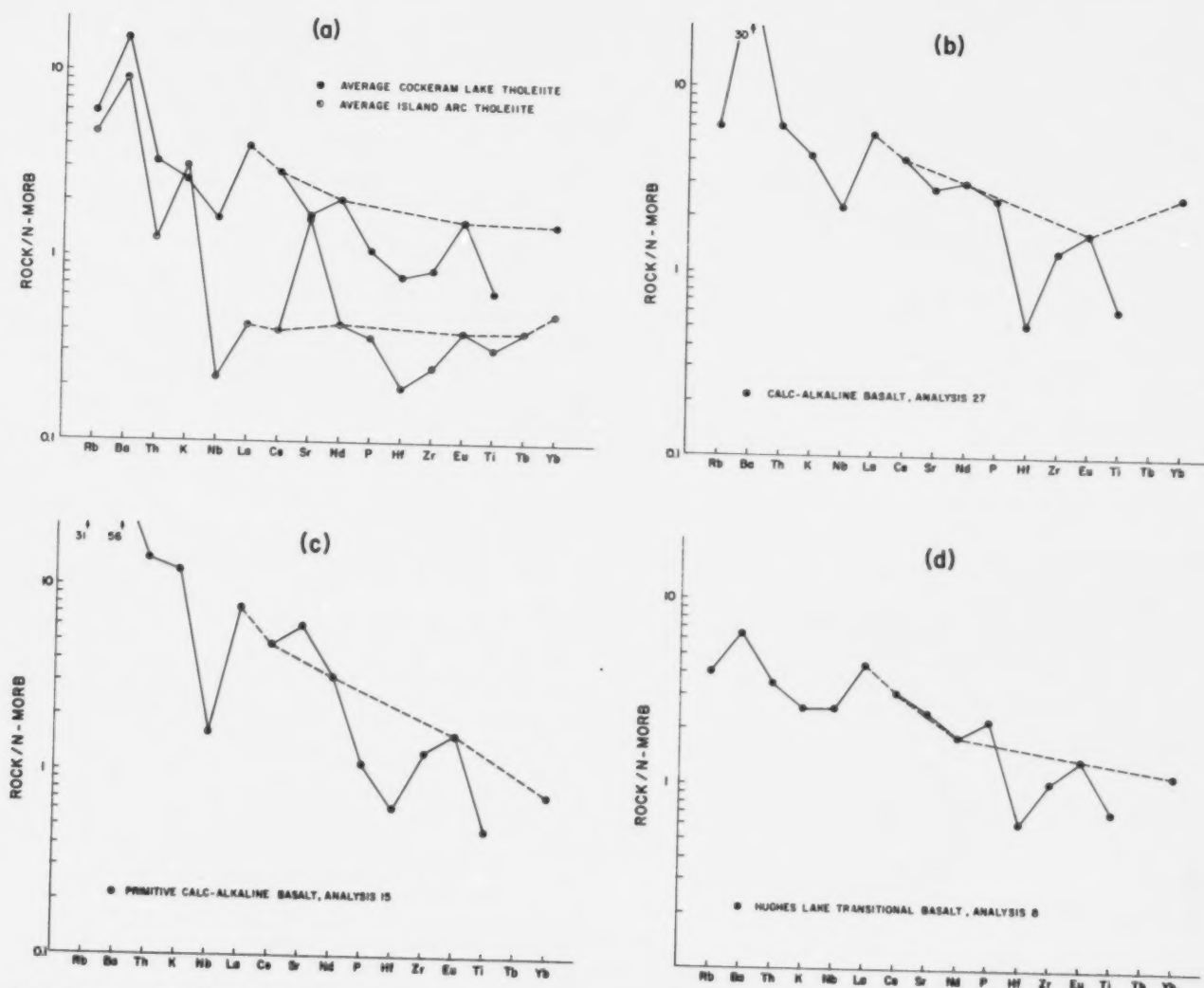
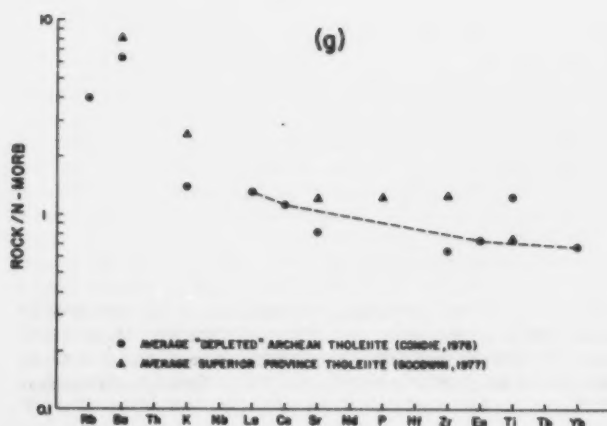
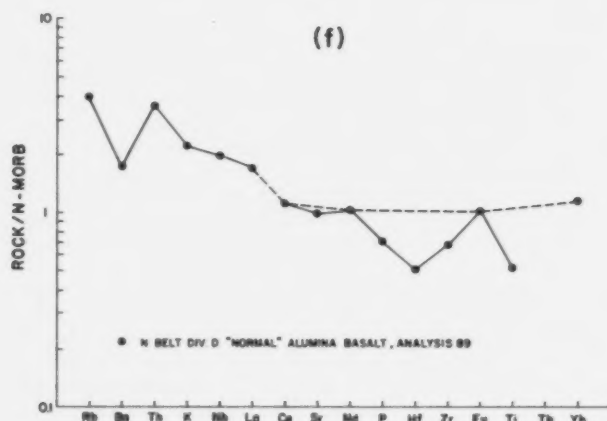
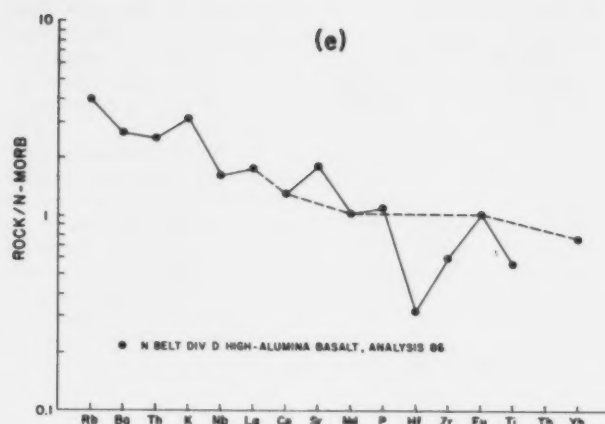


Figure 64:

Abundances of incompatible elements in Wasekwan Group basalts (a to f), average island arc basalt (g; Sun, 1980; Weaver et al., 1982) and average Archean tholeiite (h; Condie, 1976; Goodwin, 1977) normalized to average N-type MORB (Sun, 1980; Sun et al., 1979; Weaver et al., 1982). Order of elements from Weaver et al. (1982). High field strength (HFS) elements are Ti, P, Zr, Hf, Nb; large-ion lithophile (LIL) elements are Rb, Ba, Th, K, Sr; rare earth elements (REE) are La, Ce, Nd, Tb, Yb. Dashed lines represent REE positions.



indicates the "normal"- and "high"-alumina lavas in the Northern Belt are genetically related; an absence of relative Nb depletion appears to characterize these rocks.

(3) The Hughes Lake transitional basalt displays strong depletion in HFS elements Nb, Hf, Zr and Ti relative to REE; P, however, is enriched. This basalt shows no enrichment of LIL elements relative to the fractionated REE pattern; in fact, most LIL are depleted.

(4) Primitive calc-alkaline basalt (sample 15) and calc-alkaline basalt (sample 27) are characterized by strongly fractionated, LREE-enriched patterns accompanied by strong decoupling between HFS and REE. P is depleted in sample 15 but this may simply reflect choice of samples, inasmuch as the other members of this suite have much higher P contents. It is probable that the primitive calc-alkaline suite is similar to the calc-alkaline suite in a characteristic absence of P depletion. Exceptional enrichment in Rb and Ba in sample 15 may reflect LIL redistribution during alteration, as discussed previously. For sample 27, LIL elements (except Ba) are either on line with the REE trend or weakly depleted with respect to the REE trend.

The enrichment in LIL elements relative to REE which is so prominent in an "average" island arc basalt (Fig. 64a) is not evident to the same degree in Wasekwan Group rocks. There are two possible explanations: first, the absolute abundances of LIL elements in, for example, a Wasekwan tholeiite (Cockeram Lake basalt) closely match those in "average" island arc basalt but the fractionated, elevated contents of the other trace elements mask their enriched character. Second, there is clear evidence of LIL redistribution (discussed in Alteration) which may have a significant effect in some of the samples.

In view of the major geochemical differences between Archean tholeiites and Wasekwan Group tholeiites, it is interesting to note that there is no decoupling of HFS and REE in average compositions of Archean tholeiite, and LIL element abundances are not significantly enriched with respect to the REE trend (Fig. 64g). The pattern is consistent with recent models which suggest an ensialic rifting environment for Archean belts (e.g. Nesbitt and Sun, 1976; Hawkesworth and O'Nions, 1977; Thurston et al., in press). Partial melting in such an environment would be essentially anhydrous.

In summary, the Wasekwan Group displays critical geochemical and chemo-stratigraphic characteristics of the Cenozoic island arc association, and these characteristics are in general absent from Archean volcanic belts:

- (1) Presence of high-alumina basalts,
 - (2) Lower Ni and Cr in tholeiites and calc-alkaline rocks,
 - (3) Depleted HFS element (Zr, Ti, P, Nb, Hf) abundances relative to REE,
 - (4) Relatively enriched LIL element (Rb, Ba, K, Sr, Th) abundances, and
 - (5) Calc-alkaline and siliceous volcanic rocks undepleted in HREE.
- Thus, the closest modern analogue of the Wasekwan Group is considered to be an intra-oceanic island arc. Tectonic models for the western Churchill Province are consistent in a general way with this conclusion (Gibb, 1975; Camfield and Gough, 1977; Ray and Wanless, 1980; Lewry et al., 1981; Lewry, 1981).

Modern island arc tholeiitic and calc-alkaline rocks with unfractionated REE patterns are not likely to have been produced from melts separated from an eclogitic residuum (Gorton, 1977; Arth, 1981). The more strongly fractionated REE patterns exhibited by Wasekwan Group rocks (e.g., Fig. 64a) may indicate that they were derived by somewhat smaller degrees of partial melting than are modern arc magmas. The lower degree of partial melting would result in somewhat higher LIL element contents in the melts and the presence of clinopyroxene in the residuum, thereby producing more fractionated REE patterns (Gorton, 1977).

The source of tholeiitic and calc-alkaline magmas in modern intra-oceanic arcs is within the sub-arc mantle wedge; ample evidence comes from REE (Dixon and Batiza, 1979; Gorton, 1977; Arth, 1981), Sr isotope (Meijer and Reagan, 1981; Stern, 1979, 1982; Dixon and Stern, 1983),

Nd isotope (Stern, 1979; Dixon and Stern, 1983), He isotope (Stern, 1979), and Rb isotope data (Meijer and Reagan, 1981; Sun, 1980). By extending the modern analogue to the Wasekwan Group, the source of Wasekwan magmas probably lay in the early Proterozoic upper man-

tle. Future geochemical work in the Lynn Lake belt should include radiogenic isotope studies, which would further characterize the source of Wasekwan Group magmas and provide additional information on the composition of the mantle in the Proterozoic.

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Table A1:
Whole-rock chemical analyses (weight per cent), Ni and Cr (ppm), and description and location of samples
(from Gilbert et al., 1980)

	1	2	3	4	5	6	7	8	9	10
SiO ₂	52.15	49.55	55.25	52.05	53.60	50.25	51.95	49.15	50.05	48.30
Al ₂ O ₃	14.85	15.87	13.84	14.00	15.39	14.25	14.18	15.60	16.48	15.54
Fe ₂ O ₃	2.64	1.70	2.61	3.18	2.36	4.43	2.48	2.28	2.23	2.44
FeO	8.00	5.94	8.68	9.68	8.74	7.40	9.19	10.04	9.67	8.43
CaO	9.63	14.8	6.89	9.19	7.89	12.8	9.11	10.97	6.76	11.78
MgO	6.95	5.73	5.45	5.03	4.21	3.11	5.98	5.52	5.87	5.81
Na ₂ O	2.70	1.90	3.54	3.31	4.69	2.69	3.32	3.04	4.06	3.07
K ₂ O	0.56	0.14	0.53	0.25	0.25	0.22	0.43	0.33	0.35	0.41
TiO ₂	0.76	0.59	0.98	1.30	1.21	1.44	0.97	1.13	1.27	1.78
P ₂ O ₅	0.07	0	0.12	0.22	0.22	0.26	0.19	0.30	0.34	0.68
MnO	0.18	0.15	0.22	0.20	0.20	0.23	0.19	0.19	0.20	0.12
H ₂ O	1.41	1.28	1.42	1.30	0.94	1.24	1.39	1.36	2.40	1.36
S	0.03	0.07	0.28	0.04	0.04	0.08	0.03	0	0	0
CO ₂	0.07	2.12	0.12	0.08	0.12	1.12	0.59	0.19	0.10	0.28
Less O = S	0.01	0.03	0.11	0.02	0.02	0.03	0.01			
TOTAL	99.99	99.81	99.82	99.81	99.84	99.49	100.00	99.99	99.78	100.00
Ni	52	146	28	26	11	26	34	74	70	128
Cr	122	230	88	33	10	15	56	80	80	270
FeO*/MgO	1.49	1.30	2.02	2.49	2.58	3.66	1.91	2.19	1.99	1.83

COCKERAM LAKE APHYRIC BASALT (Unit 2; analyses 1 to 7)

- 1 Pillowed basalt, 1.5 km S of Cockeram Lake (52-6-315-1). Well foliated, primary texture obliterated.
- 2 Pillowed basalt, SE shore of Cockeram Lake (52-6-346-1). Pillow margin; primary randomly-oriented plagioclase microlite texture preserved. Carbonate and epidote in fractures.
- 3 Basalt, 2 km N of Moses Lake (52-6-373-2). Primary microlitic texture preserved, a few plagioclase and polymineralic amygdaloids.
- 4 Pillowed basalt, 1.5 km NE of Moses Lake (52-6-391-1). Unfoliated, primary randomly-oriented plagioclase microlite texture preserved. 1% plagioclase-filled amygdaloids.
- 5 Pillowed basalt, 1.5 km NE of Moses Lake (52-6-416-1). 7% hornblende pseudomorphs after pyroxene phenocrysts (0.1 - 0.7 mm), in a microlitic groundmass. Unfoliated. 3% polymineralic amygdaloids.
- 6 Massive basalt, 2 km NE of Moses Lake (52-6-421-1). Unfoliated, randomly-oriented plagioclase microlite texture, 2% quartz and quartz-carbonate amygdaloids.
- 7 Fine to medium grained, gneissoid amphibolite, 750 m south of Ace Lake (32-6-83-1). Minor carbonate fracture filling (3%).

HUGHES LAKE APHYRIC BASALT (Unit 2; analyses 8 to 11)

- 8 Massive basalt, 1.5 km NW of One Island Lake (52-7-1425-1). 40% irregular amphibole aggregates, 5% plagioclase-filled amygdaloids.
- 9 Massive basalt, 0.5 km NE of Hill Lakes (52-7-1335-1). Felted mass of fibrous hornblende with very fine grained interstitial plagioclase; a few amphibole aggregates. 5% plagioclase-filled and polymineralic amygdaloids.
- 10 Massive basalt, 1.7 km NW of One Island Lake (52-7-1438-2). Primary randomly-oriented plagioclase lath texture preserved. 10% hornblende pseudomorphs after pyroxene phenocrysts (1 - 1.5 mm).

*Total Fe calculated as FeO

Table A1:
Whole-rock chemical analyses (weight per cent), Ni and Cr (ppm), and description and location of samples. (continued)

	11	12	13	14	15	16	17	18	19	20
SiO ₂	48.10	45.75	57.20	49.60	46.80	53.25	47.30	52.30	49.55	47.30
Al ₂ O ₃	15.20	16.83	16.12	15.72	16.09	14.23	13.97	13.80	16.05	16.26
Fe ₂ O ₃	3.14	2.10	2.14	4.44	3.57	2.64	2.92	3.41	1.78	3.21
FeO	7.76	10.96	5.88	5.92	5.66	6.28	9.11	9.89	8.83	7.90
CaO	10.79	12.07	8.07	10.3	12.1	9.19	11.21	8.48	12.76	16.00
MgO	7.00	7.03	4.39	5.93	8.62	6.01	8.81	5.54	5.64	4.61
Na ₂ O	3.04	1.85	3.44	1.91	1.89	4.39	1.56	2.58	1.57	0.76
K ₂ O	0.29	0.43	0.82	2.02	1.56	0.48	1.65	0.63	0.32	0.20
TiO ₂	0.87	0.89	0.72	1.06	0.74	0.98	1.06	1.36	0.87	0.77
P ₂ O ₅	0.23	0.19	0.14	0.30	0.15	0.29	0.28	0.13	0.08	0.08
MnO	0.17	0.19	0.14	0.18	0.15	0.21	0.23	0.25	0.17	0.29
H ₂ O	1.94	1.57	1.17	1.70	1.83	0.99	1.83	1.41	1.43	1.58
S	0	0.02	tr	0.01	0.01	0.02	0.01	0.07	tr	tr
CO ₂	1.45	0.12	0.14	0.37	0.55	0.66	0.14	0.12	0.71	1.16
Less O = S		0.01				0.01		0.03		
TOTAL	99.98	99.99	100.37	99.46	99.72	99.61	100.08	99.94	99.76	100.12
Ni	66	136	70	30	72	44	65	16	42	18
Cr	270	116	56	178	300	264	362	24	200	144
FeO*/MgO	1.51	1.83	1.78	1.67	1.03	1.44	1.33	2.34	1.85	2.34

- 11 Massive basalt, SE shore of Hughes Lake (52-7-1241-1). Contains ovoid fragments (up to 2 cm) of pyroxene-phyrlic and plagioclase-phyrlic basalt in a microscopically inhomogeneous basaltic matrix.

MISKWA LAKE APHYRIC BASALT (Unit 2; analyses 12 to 13)

- 12 Mafic tuff, 2.5 km SSE of Miskwa Lake (52-7-1554-1). Layering (5 mm - 10 cm) defined by ratio of hornblende to plagioclase and quartz. Approximately 75-80% hornblende.

- 13 Amphibolite, 1.5 km S of Miskwa Lake (52-7-1568-1). Fine grained mosaic of subidioblastic, oriented hornblende, equant irregular plagioclase, and blebby quartz. Intruded by diorite and quartz diorite dykes.

McVEIGH LAKE PORPHYRITIC BASALT (Unit 3, analyses 14 to 18)

- 14 Massive porphyritic basalt, 1 km W of McVeigh Lake (52-6-25-1). 25% hornblende pseudomorphs after primary pyroxene phenocrysts (2 - 10 mm), a few relicts of 1 mm plagioclase phenocrysts. 20% biotite.

- 15 Massive porphyritic basalt, 0.7 km NW of McVeigh Lake (52-6-876-1). 25% hornblende pseudomorphs after primary pyroxene phenocrysts (to 3 mm), 30% lath-shaped plagioclase phenocrysts (0.5 - 0.7 mm). 5% biotite.

- 16 Massive porphyritic basalt, 0.6 km W of S end of McVeigh Lake (52-6-126-2). 30% hornblende pseudomorphs after primary pyroxene phenocrysts (to 2 mm), 20% lath-shaped plagioclase phenocrysts (to 2 mm). Unfoliated. 1% biotite.

- 17 Massive porphyritic basalt, 200 m W of N end of McVeigh Lake (52-6-877-1). 30% hornblende pseudomorphs after pyroxene phenocrysts (2 - 7 mm), indistinct 1 - 2 mm plagioclase phenocrysts. 10% biotite.

- 18 Massive aphyric basalt apparently intercalated with porphyritic basalt, Elb Lake (52-6-95-1). Recrystallized; remnants of fine-grained (0.5 - 1 mm) diabasic texture.

MISKWA LAKE PORPHYRITIC BASALT (Unit 3; analyses 19 to 23)

- 19 Porphyritic basalt flow breccia (massive magmatic matrix analysed), 2.6 km SE of Miskwa Lake (52-7-1524-1). 20% hornblende pseudomorphs after pyroxene phenocrysts (1 - 5 mm), 20% subhedral plagioclase phenocrysts (0.5 - 1.5 mm). Relict clinopyroxene and labradorite. 1% quartz amygdaloids.

- 20 Porphyritic basalt flow breccia, 4.1 km SE of Miskwa Lake (52-7-1217-1). Porphyritic fragments with quartz amygdaloids (colour index 40) in a porphyritic matrix (colour index 60). Pyroxene (pseudomorphed by hornblende) and plagioclase phenocrysts.

Table A1:
Whole-rock chemical analyses (weight per cent), Ni and Cr (ppm), and description and location of samples. (continued)

	21	22	23	24	25	26	27	28	29	30
SiO ₂	51.45	54.30	56.60	49.40	54.65	53.25	53.70	49.55	50.90	58.00
Al ₂ O ₃	16.83	14.12	14.55	18.65	15.62	13.92	16.59	16.56	16.78	16.48
Fe ₂ O ₃	3.37	2.97	2.82	3.76	2.35	4.08	3.27	5.11	4.18	1.43
FeO	7.42	10.67	9.47	5.92	8.87	11.80	5.60	5.98	5.92	5.80
CaO	9.87	8.12	8.09	12.23	5.59	7.24	7.76	8.81	6.19	5.69
MgO	5.01	3.81	3.19	4.60	4.44	3.86	5.69	6.25	6.36	4.42
Na ₂ O	3.24	3.38	3.13	2.49	3.59	1.64	3.38	3.22	4.27	6.32
K ₂ O	0.26	0.36	0.34	0.27	0.20	0.52	0.55	0.77	0.39	0.30
TiO ₂	0.73	0.92	0.72	0.63	1.03	0.67	0.97	1.11	1.23	0.75
P ₂ O ₅	0.04	0.04	0.05	0.11	0.31	0.15	0.34	0.33	0.44	0.20
MnO	0.21	0.16	0.14	0.20	0.28	0.37	0.15	0.14	0.11	0.10
H ₂ O	1.28	1.22	1.11	1.74	2.81	2.24	1.95	1.83	2.50	0.96
S	0.03	0	0.02	0.01	tr	0.05	0.14	tr	0.04	0.01
CO ₂	0.07	0.07	0.07	0.42	0.37	0.07	0.07	0.12	0.10	0.12
Less O = S	0.01		0.01			0.02	0.06		0.02	
TOTAL	99.80	100.14	100.29	100.43	100.11	99.84	100.10	99.78	99.39	100.58
Ni	14	18	10	30	<8	10	80	70	58	58
Cr	40	8	8	40	<6	48	132	231	70	50
FeO*/MgO	2.08	3.50	3.76	2.02	2.48	4.01	1.50	1.86	1.52	1.60

21 Massive plagioclase-phyric basalt, SE end of Wasekwan Lake (52-7-1710-3). 10% recrystallized plagioclase phenocrysts (1 - 3 mm) in a fine grained groundmass.

22 Massive aphyric basalt, 2 km SE of Wasekwan Lake (52-7-1725-1). Rare hornblende aggregates after primary mafic phenocrysts; moderate foliation.

23 Massive aphyric basalt or basaltic andesite, Wiley Lakes (52-7-1730-1). Good hornblende foliation, no primary texture preserved. 3% ovoid quartz aggregates (0.2 - 0.5 mm); possible amygdalites.

KEEWATIN RIVER MAFIC TO INTERMEDIATE VOLCANIC ROCKS (Unit 4; analyses 24 to 26)

24 Massive aphyric basalt, 1.5 km E of N end of Sickle Lake (52-7-1790-1). Fine grained, completely recrystallized, poorly foliated.

25 Massive aphyric basalt, 4 km NE of Sickle Lake (52-7-1157-1). Very fine grained, completely recrystallized, a few quartz-carbonate-plagioclase stringers.

26 Mafic tuff, 3.5 km NNE of Sickle Lake (52-7-1155-1). 10% pseudomorphs after plagioclase phenocrysts (to 1 mm). Good hornblende foliation.

HUGHES LAKE CALC-ALKALINE SUITE (analyses 27 to 47)

1. **East of Hughes Lake** (analyses 27 to 34), in stratigraphic sequence from base to top.

27 Massive aphyric basalt (Lower Series), 3.5 km NNW of One Island Lake (52-7-1457-1). No primary texture preserved; poorly foliated.

28 Massive aphyric basalt (Lower Series), 1.5 km E of Hughes Lake (52-7-1270-1). No primary texture preserved.

29 Massive aphyric basalt (Lower Series), 0.5 km E of Hughes Lake (52-7-1274-1). 1-2% plagioclase phenocrysts (0.4 mm) in groundmass of plagioclase microlites and very fine grained felted amphibole. 3% quartz-epidote amygdalites.

30 Massive porphyritic andesite (Upper Series), 760 m E of Hughes Lake (52-7-1309-1). Small (0.5 mm) plagioclase and hornblende (after pyroxene?) phenocrysts in an inhomogeneous groundmass of plagioclase microlites, locally abundant plagioclase spherulites, and amphibole.

Table A1:
Whole-rock chemical analyses (weight per cent), Ni and Cr (ppm), and description and location of samples. (continued)

	31	32	33	34	35	36	37	38	39	40
SiO ₂	59.60	61.50	57.30	56.85	57.00	57.15	54.85	57.55	62.05	63.40
Al ₂ O ₃	15.57	17.65	16.56	17.62	16.59	16.69	18.10	15.56	16.50	15.01
Fe ₂ O ₃	1.09	2.29	0.69	0.97	2.64	1.75	1.54	1.48	0.89	1.10
FeO	5.72	3.52	5.14	3.57	5.46	5.76	4.44	5.50	3.74	3.75
CaO	7.90	5.71	9.08	10.13	5.16	6.98	8.20	7.72	6.56	5.58
MgO	3.91	2.36	3.98	3.98	4.24	4.17	4.38	4.05	2.38	2.72
Na ₂ O	3.32	3.99	4.74	5.24	3.42	2.90	5.02	2.98	4.78	3.45
K ₂ O	0.37	0.70	0.36	0.20	0.82	0.98	0.53	0.99	0.62	1.30
TiO ₂	0.82	0.61	0.76	0.74	0.86	0.80	0.70	0.73	0.90	0.69
P ₂ O ₅	0.31	0.21	0.25	0.22	0.17	0.28	0.17	0.25	0.19	0.22
MnO	0.14	0.09	0.09	0.07	0.13	0.15	0.07	0.16	0.07	0.09
H ₂ O	0.97	1.24	0.77	0.72	3.19	2.27	1.57	1.74	0.95	1.49
S	tr	tr	0	0	0	0.04	0.02	0.22	0.11	0.01
CO ₂	0.16	0.10	0.05	0.14	0.41	0.14	0.26	0.54	0.11	0.89
Less O ≡ S						0.02	0.01	0.09	0.04	
TOTAL	99.88	99.97	99.77	100.45	100.09	100.04	99.84	99.38	99.81	99.70
Ni	66	35	66	66	38	66	50	80	24	50
Cr	56	32	82	74	48	82	112	90	72	98
FeO*/MgO	1.71	2.37	1.45	1.11	1.85	1.76	1.33	1.69	1.91	1.74

31 Massive plagioclase-phyric andesite (Upper Series), 2.3 km NW of One Island Lake (52-7-1447-1). 15% corroded plagioclase phenocrysts (0.5 - 1.5 mm) in a groundmass of plagioclase microlites (0.2 - 0.4 mm) and fine grained hornblende.

32 Massive plagioclase-phyric andesite (Upper Series), 670 m E of Hughes Lake (52-7-1326-1). 5-10% subhedral plagioclase phenocrysts (0.5 - 2 mm). Relict pilotaxitic texture locally preserved. Amphibole blastesis (3%).

33 Massive plagioclase-phyric andesite (Upper Series), 2.1 km NW of One Island Lake (52-7-1444-1). 10% euhedral plagioclase phenocrysts (0.5 - 1.5 mm) in a groundmass of felted plagioclase microlites and fine-grained amphibole.

34 Massive porphyritic andesite (Upper Series), 2.1 km NW of One Island Lake (52-7-1439-5). Euhedral phenocrysts of plagioclase (25%, 0.3 - 2 mm) and amphibole after pyroxene (10%, 0.2 - 0.5 mm) in a fine-grained, recrystallized groundmass.

2. Pole Lake Area (analyses 35 to 40)

35 Pillowed andesite, 500 m S of Pole Lake (52-6-223-1). Mosaic of epidotized, recrystallized plagioclase crystals (0.2 - 0.8 mm) with interstitial biotite, chlorite, quartz, epidote.

36 Massive porphyritic andesite, 100 m N of Pole Lake (52-6-642-1). Phenocrysts of plagioclase (15-20%, 0.5 - 3 mm) and amphibole after pyroxene (2%, 0.2 - 0.6 mm) in a microlitic, weakly amygdaloidal (2%) groundmass.

37 Aphyric andesite fragment in pyroclastic breccia, 800 m E of Pole Lake (52-6-684-2). Pilotaxitic texture; a few carbonate and polymineralic amygdaloids.

38 Massive porphyritic andesite, 400 m NE of Pole Lake (52-6-650-1). Phenocrysts of plagioclase (5%), quartz (3%), and amphibole (2%) in a groundmass dominated by felted plagioclase microlites.

39 Massive porphyritic dacite, 1.8 km NE of Pole Lake (52-6-668-1). Phenocrysts of plagioclase (10%, up to 1.5 mm) and quartz (1%, up to 0.7 mm) in a groundmass dominated by felted plagioclase microlites.

40 Massive porphyritic dacite, 400 m NE of Pole Lake (52-6-647-1). Phenocrysts of plagioclase (2%, 1-2 mm) and quartz (2%, 1 mm) in a groundmass dominated by plagioclase microlites. 5% quartz-carbonate amygdaloids.

Table A1:
Whole-rock chemical analyses (weight per cent), Ni and Cr (ppm), and description and location of samples. (continued)

	41	42	43	44	45	46	47	48	49	50
SiO ₂	65.80	77.30	76.50	76.80	76.30	75.35	74.50	65.85	69.25	61.05
Al ₂ O ₃	15.72	12.86	12.69	11.25	12.62	13.21	13.10	14.84	13.16	14.54
Fe ₂ O ₃	1.86	0.13	0.44	0.76	0.43	0.73	1.09	1.84	1.61	2.52
FeO	3.03	0.42	0.64	0.94	0.86	0.96	1.16	3.87	4.55	5.14
CaO	3.96	0.12	0.70	1.29	1.02	2.15	1.32	4.15	2.90	5.62
MgO	1.16	0.02	0.14	0.30	0.08	0.68	0.64	1.68	0.91	2.41
Na ₂ O	5.07	4.48	3.82	2.81	4.94	3.55	3.97	3.70	3.84	2.89
K ₂ O	1.18	3.73	3.73	3.57	2.36	1.55	2.26	1.77	1.47	1.53
TiO ₂	0.82	0.07	0.08	0.12	0.06	0.27	0.31	0.58	0.51	0.80
P ₂ O ₅	0.30	0	0	0	0	0.03	0.02	0.14	0.14	0.28
MnO	0.08	0.01	0.03	0.04	0.03	0.03	0.30	0.12	0.12	0.15
H ₂ O	0.66	0.44	0.60	0.74	0.39	0.82	1.02	1.08	0.93	1.67
S	0.06	0.01	tr	0.03	0	0	0	0.07	0	0.02
CO ₂	0.23	0.25	0.55	1.05	0.61	0.34	0.71	0.19	0.38	1.16
Less O ≡ S	0.02			0.01				0.03		0.01
TOTAL	99.91	99.84	99.92	99.69	99.70	99.67	100.40	99.85	99.77	99.77
Ni	<8	<4	10	<4	<6	6	14	10	6	14
Cr	<6	15	<8	<10	<8	<8	<8	8	<8	8
FeO*/MgO	4.06	26.85	7.4	5.4	15.59	2.38	3.35	3.29	6.59	3.07

3. Dacite

- 41 Massive plagioclase-phyric dacite, 500 m E of Hughes Lake (52-7-1257-1). 10% plagioclase phenocrysts (0.7 - 2 mm) in a groundmass dominated by feldt plagioclase microlites; a few quartz aggregates (1 mm).

4. Rhyolite (analyses 42 to 47)

- 42 Porphyritic rhyolite, 1.6 km E of Cartwright Lake (52-6-213-1). Phenocrysts of plagioclase (3%, 0.6 - 1.3 mm) and quartz (1%, 0.6 - 1 mm) in a very fine grained matrix of quartz, feldspar, sericite, and minor biotite.
- 43 Porphyritic rhyolite, 1.6 km E of Cartwright Lake (52-7-1768-2). Phenocrysts of plagioclase (2%, to 2 mm) and quartz (2%, to 1 mm) in a very fine grained groundmass as above. Flow-laminated.
- 44 Aphyric rhyolite, 1.5 km E of Pole Lake (52-6-694-1). Very fine grained mosaic of quartz, feldspar, sericite, minor biotite.
- 45 Aphyric rhyolite, 2.2 km NW of One Island Lake (52-7-1443-1). Plagioclase laths (0.1 - 0.2 mm) are in a very fine grained groundmass of quartz, feldspar, sericite, minor biotite, and minor carbonate.
- 46 Aphyric rhyolite, 300 m N of Hughes Lake, W of Hughes River (52-7-1629-2). From a massive flow 18 m thick. Rare plagioclase phenocrysts (0.5 mm) in a very fine grained recrystallized groundmass. 5% polymineralic (carbonate-quartz) amygdaloids.
- 47 Porphyritic rhyolite, E side of Chepil Lake (52-7-1824-2). 15% plagioclase phenocrysts and glomerocrysts (0.5 - 3 mm) in a very fine grained mosaic of lath-shaped plagioclase (0.1 mm), quartz, feldspar, sericite, and biotite.

KEEWATIN RIVER DACITE (analyses 48 to 50)

- 48 Porphyritic dacite, E side of Keewatin River, 2 km N of Sickle Lake (52-7-1076-1). 5-10% plagioclase phenocrysts (0.3 - 1 mm) in a very fine grained, foliated groundmass of feldspar, quartz, biotite, epidote, and magnetite. Rare small quartz amygdaloids.
- 49 Porphyritic dacite, 4 km N of Sickle Lake (52-7-1084-1). 10-15% plagioclase phenocrysts (0.5-2 mm) in a very fine grained recrystallized ground mass. Good foliation; 1% garnet.
- 50 Dacitic tuff, 3 km N of Sickle Lake (52-7-1080-1). 10% euhedral plagioclase crystals and angular crystal fragments, aphyric lithic fragments and porphyritic lithic fragments in an intermediate matrix. 3% carbonate.

Table A1:
Whole-rock chemical analyses (weight per cent), Ni and Cr (ppm), and description and location of samples. (continued)

	51	52	53	54	55	56	57	58	59	60	61
SiO ₂	58.50	71.00	63.85	71.90	75.35	50.35	50.70	49.10	48.30	48.45	56.20
Al ₂ O ₃	18.50	13.42	15.32	12.53	11.70	15.48	13.34	15.70	14.97	15.21	15.93
Fe ₂ O ₃	2.75	1.10	1.15	1.47	1.05	2.62	1.95	2.41	2.73	1.69	1.99
FeO	3.75	4.07	6.52	4.05	2.93	8.54	8.12	9.39	10.22	9.91	5.14
CaO	7.70	1.51	6.37	2.98	0.65	10.6	12.0	10.37	9.41	9.08	7.84
MgO	1.76	0.91	1.66	0.98	1.21	7.36	8.17	6.82	7.73	7.67	5.34
Na ₂ O	3.01	4.81	1.85	3.60	4.31	2.32	2.13	3.14	2.29	2.37	3.47
K ₂ O	1.60	1.43	0.94	0.78	1.53	0.09	0.21	0.28	0.53	0.72	0.84
TiO ₂	0.49	0.40	0.55	0.45	0.20	0.46	0.70	1.09	1.15	1.47	0.63
P ₂ O ₅	0.07	0.09	0.12	0.10	0.01	0.04	0.05	0.28	0.28	0.56	0.21
MnO	0.13	0.10	0.18	0.12	0.04	0.19	0.21	0.17	0.21	0.20	0.13
H ₂ O	1.30	0.97	1.00	0.76	0.79	1.50	1.45	1.38	2.25	2.15	1.90
S	0.0	0.01	0.02	0.03	0.01	0.02	0.01	0.01	0	0	0
CO ₂	0.13	0.10	0.14	0.05	0.08	0.08	0.84	0.17	0.07	0.07	0.22
Less O = S			0.01	0.1		0.01					
TOTAL	99.69	99.92	99.66	99.79	99.86	99.64	99.88	100.31	100.14	99.55	99.84
Ni			<6	6	10	80	62	94	86	144	76
Cr			8	<8	<8	192	136	276	228	292	134

SEDIMENTARY ROCKS (analyses 51 to 55)

- 51 Feldspathic greywacke, 2 km N of Sickle Lake (52-7-1075-1). Intercalated with mafic flows of unit 4. Remnants of clastic texture preserved.
- 52 Massive homogeneous siltstone, 2.5 km N of Sickle Lake (52-7-1094-1). Very fine grained, 3% plagioclase microclasts (to 0.3 mm).
- 53 Laminated siltstone, 2.4 km NW of Sickle Lake (52-7-1208-3). From the thin sedimentary formation within unit 3 porphyritic basalt. Lamination defined by amphibole content and ratio of amphibole to biotite. 3% garnet.
- 54 Laminated siltstone, 4 km NW of Sickle Lake (52-7-1520-1). Same sedimentary formation as above. 2% garnet.
- 55 Feldspathic greywacke, 1.3 km SW of Miskwa Lake (52-7-1580-1). Very good clastic texture. Poorly sorted, fine to medium sand grade. Rich in plagioclase crystal fragments.

GABBRO (Unit 13, analyses 56 to 60)

- 56 Porphyritic gabbro, sill, 600 m NW of Foster Lake (52-6-120-2). Finer grained gabbro units (1.5 mm grain size; this analysis) alternate with coarsely porphyritic (5 mm) gabbro; units 6 - 9 m thick.
- 57 Densely porphyritic gabbro, 1 km S of Cockeram Lake (52-6-298-1). From the gabbro pluton which cores the McVeigh Lake anticline. Blocky hornblende pseudomorphs (1.5 mm) with interstitial plagioclase.
- 58 Gabbro sill, 1.1 km of One Island Lake (52-7-1651-1). Lath-shaped plagioclase crystals (0.5 - 1 mm), subhedral and interstitial amphibole. Grades to 59, below.
- 59 Ophitic gabbro, sill, 1.1 km NW of One Island Lake (52-7-1651-2). Hornblende (after pyroxene) oikocrysts to 6 mm diameter enclose lath-shaped plagioclase crystals 0.5 - 1 mm long.
- 60 Gabbro, pluton, 2.7 km NW of One Island Lake (52-7-1448-1). Lath-shaped plagioclase (0.6 mm), amphibole aggregates after primary pyroxene oikocrysts.

QUARTZ DIORITE (Unit 14)

- 61 Quartz diorite plug intrusive into the Hughes Lake calc-alkaline suite, Cartwright Lake (52-6-838-1). Fine grained (1 mm), with subhedral plagioclase, anhedral to subhedral amphibole (25%), interstitial quartz, leucoxene, epidote.

Table A1:
Whole-rock chemical analyses (weight per cent), Ni and Cr (ppm), and description and location of samples. (continued)

	62	63	64	65	66	67	68	69	70	71
SiO ₂	50.45	51.45	51.75	52.35	52.45	52.45	52.65	53.35	53.75	54.10
Al ₂ O ₃	13.09	18.54	18.60	21.38	14.23	18.08	16.22	19.12	19.33	15.56
Fe ₂ O ₃	2.07	2.12	2.66	1.14	2.22	2.37	1.91	1.36	1.73	2.25
FeO	9.44	8.18	8.52	6.78	8.07	9.36	10.67	6.64	7.39	8.92
CaO	10.75	6.66	9.97	10.65	9.23	8.26	5.76	9.49	8.55	8.40
MgO	6.62	3.45	2.62	2.36	6.11	3.18	4.51	3.55	2.99	3.81
Na ₂ O	3.40	4.74	2.26	2.29	4.23	1.95	3.00	3.18	3.09	2.50
K ₂ O	0.31	1.77	0.50	0.43	0.39	1.38	1.39	0.24	0.55	0.90
TiO ₂	1.69	0.98	1.03	0.90	1.44	1.00	1.23	1.04	0.88	0.79
P ₂ O ₅	0.14	0.35	0.17	0.17	0.26	0.20	0.19	0.24	0.18	0.14
MnO	0.20	0.20	0.25	0.18	0.17	0.19	0.20	0.20	0.17	0.21
H ₂ O	1.21	1.13	1.00	1.16	1.17	1.49	1.77	0.97	1.23	1.39
S	tr	0.02	0.01	NIL			tr	0.01		0.10
CO ₂	0.64	0.15	0.07	0.37	0.11	0.09	0.15	0.18	0.16	0.90
Less O = S		0.01								0.04
TOTAL	100.01	99.73	99.41	100.16	100.08	100.00	99.65	99.57	100.00	99.93
Ni	108	<6	<6	6	84	3	6	10	<1	<6
Cr	350	8	16	8	292	<10	16	40	<10	16
FeO*/MgO	1.71	2.92	4.16	3.31	1.65	3.61	2.75	2.21	2.99	2.87

NORTHERN BELT: DIVISION A (analyses 77 and 78)
: **DIVISION B** (analyses 62 to 76)

Unit 4; analyses 62 to 74

- 62 Massive, fine to medium grained, gneissoid amphibolite, 2 km west-southwest of Bob Lake (32-6-779-1).
- 63 Porphyritic basalt, 2 km southeast of Minton Lake (32-6-975-1). 20% plagioclase phenocrysts in a well foliated matrix of quartz and plagioclase (70%), biotite (15%) and hornblende (15%).
- 64 Porphyritic basalt, 300 m south of the south end of Margaret Lake (32-6-286-1). 25% plagioclase phenocrysts in a very fine grained amphibolite matrix with minor quartz aggregates (amygdaloidal?).
- 65 Porphyritic basalt, 1.5 km southwest of the south end of Minton Lake (32-6-651-1). 35% plagioclase phenocrysts in a massive amphibolite matrix of very fine grained quartz and plagioclase with medium grained hornblende porphyroblasts.
- 66 Pillowed basalt, souther part of Frances Lake (32-6-251-1). 10% plagioclase phenocrysts and 15% hornblende crystals and aggregates in a fine grained amphibolite matrix.
- 67 Porphyritic basalt, northern part of Frances Lake (32-6-254-1). 20% plagioclase phenocrysts in a slightly foliated amphibolite matrix with 10% biotite and medium grained hornblende porphyroblasts.
- 68 Sparsely porphyritic basalt, north end of Frances Lake (32-6-257-1). 4% plagioclase phenocrysts in a well foliated quartz-plagioclase matrix with biotite (10%) overprinted by hornblende porphyroblasts (30%).
- 69 Porphyritic basalt-andesite, 2 km east of Eric Lake (32-6-604-6). 30% plagioclase phenocrysts, 5% hornblende pseudomorphs and 5% quartz amygdales in a well foliated amphibolite matrix.
- 70 Porphyritic basalt, 1 km southwest of Minton Lake (32-6-650-2). 25% plagioclase phenocrysts in a very fine grained quartz-plagioclase matrix overprinted by porphyroblasts of hornblende (25%) and biotite (7%). Minor quartz aggregates and stringers (<5%).
- 71 Porphyritic andesite, between Lynn River and West Lynn Lake (32-6-460-1). 15% plagioclase phenocrysts in a very fine grained quartz-plagioclase-biotite matrix with hornblende porphyroblasts and irregular quartz aggregates (5%), possibly amygdaloidal.

Table A1:

Whole-rock chemical analyses (weight per cent), Ni and Cr (ppm), and description and location of samples. (continued)

	72	73	74	75	76	77	78	79	80	81
SiO ₂	58.05	58.05	58.35	60.85	81.85	74.55	75.20	47.10	48.25	48.50
Al ₂ O ₃	19.80	18.05	17.58	16.16	9.98	12.50	12.14	20.60	19.70	20.50
Fe ₂ O ₃	0.85	1.11	2.14	3.25	0.45	0.86	0.26	1.69	1.97	2.17
FeO	5.04	5.92	5.60	4.66	1.06	2.11	1.89	8.55	7.11	8.39
CaO	8.79	8.94	9.07	4.69	0.53	0.57	1.79	11.31	13.80	10.78
MgO	1.97	2.89	2.19	2.07	0.49	0.69	0.79	4.56	4.45	3.55
Na ₂ O	3.07	2.03	2.89	4.49	4.52	3.16	1.84	2.09	1.48	3.35
K ₂ O	0.33	0.70	0.36	1.36	0.68	4.83	4.35	0.99	0.31	0.35
TiO ₂	0.88	0.84	0.65	0.72	0.14	0.18	0.14	0.77	0.57	0.78
P ₂ O ₅	0.22	0.22	0.16	0.12	0.05	0.05	0.03	0.10	0.06	0.08
MnO	0.12	0.14	0.17	0.12	0.02	0.06	0.05	0.19	0.15	0.16
H ₂ O	0.74	0.81	0.70	0.76	0.33	0.41	0.48	1.69	1.19	1.10
S				0.01					0.01	
CO ₂	0.15	0.08	0.06	0.71	0.07	0.10	0.51	0.10	0.66	0.28
Less O = S										
TOTAL	100.01	99.78	99.92	99.97	100.17	100.07	99.47	99.74	99.71	99.99
Ni	<1	6	3	10	1	<1	<1	6	15	9
Cr	10	24	18	40	<10	14	<10	24	48	14
FeO*/MgO	2.94	2.39	3.46	3.66	2.98	4.17	2.68	2.21	2.00	2.91

72 Felsic andesite, 100 m northeast of Lynn Lake hospital (32-6-498-1). Clast in polymictic breccia, containing 30% plagioclase phenocrysts in a very fine grained matrix overprinted by hornblende porphyroblasts.

73 Aphyric felsic andesite, 2 km east of Eric Lake (32-6-606-2). Very fine grained quartz and plagioclase, with hornblende porphyroblasts (15%), and biotite (10%); minor hornblende stringers.

74 Felsic andesite, 1.5 km east of Eric Lake (32-6-598-1). 25% plagioclase phenocrysts and 10% hornblende pseudomorphs in a slightly foliated matrix with 5% quartz stringers and aggregates (amygdaloidal?).

Unit 6

75 Porphyritic dacite, at Lynn River, west of West Lynn Lake (32-6-459-1). 20% plagioclase phenocrysts in a very fine grained quartz-plagioclase-biotite matrix with hornblende porphyroblasts, magnetite (8%), and carbonate (4%).

Unit 7: analyses 76 to 78

76 Quartz-rich rhyolite, northern part of Frances Lake (32-6-258-3). Boulder with flow-breccia, containing 15% plagioclase phenocrysts and 2% carbonate.

77 Porphyritic rhyolite, central Frances Lake (32-6-264-1). Plagioclase and quartz phenocrysts (10% each) occur in a well foliated matrix with biotite.

78 Porphyritic rhyolite, south end of West Lynn Lake (32-6-884-1). Very fine grained quartz-plagioclase-biotite-muscovite rock with phenocrysts of quartz and plagioclase, muscovite porphyroblasts, and 3% carbonate. Biotite occurs in very fine fracture fillings and in mafic granules (7%).

NORTHERN BELT: DIVISION D (analyses 79 to 92)

DIVISION E (analyses 93 to 95)

Unit 4: analyses 79 to 90

79 Porphyritic basalt, 5.5 km northeast of Desjeyes Lake (32-6-505-1). Phenocrysts of plagioclase (35%) and biotite (5%) and hornblende pseudomorphs after pyroxene (5%) in a well foliated, hornblende matrix with 5% magnetite.

80 Porphyritic basalt, 1 km north of the northern part of Arbour Lake (32-7-2116-1). 40% plagioclase phenocrysts in a massive hornblende-rich matrix.

81 Porphyritic basalt at the south end of Ralph Lake (32-6-139-3). From massive zone within flow-breccia; contains 40% plagioclase phenocrysts and aggregates in a well foliated amphibolite matrix with medium grained hornblende porphyroblasts and 5% magnetite.

Table A1:
Whole-rock chemical analyses (weight per cent), Ni and Cr (ppm), and description and location of samples. (continued)

	82	83	84	85	86	87	88	89	90	91
SiO ₂	48.80	48.95	49.35	49.50	49.95	51.25	51.80	52.25	53.30	69.15
Al ₂ O ₃	15.45	16.73	14.36	12.63	18.13	15.20	18.65	14.56	18.62	16.25
Fe ₂ O ₃	1.84	2.02	1.45	3.16	2.17	2.55	1.94	1.50	2.08	0.74
FeO	7.81	9.06	8.80	7.39	9.06	7.67	8.96	11.01	7.27	1.97
CaO	11.44	11.63	12.63	15.90	9.60	13.08	7.83	10.18	6.71	3.47
MgO	10.01	6.86	10.17	5.95	5.11	6.15	4.47	6.34	5.68	1.29
Na ₂ O	1.76	1.79	1.15	0.78	3.16	1.51	3.54	1.23	2.80	4.59
K ₂ O	0.27	0.30	0.15	0.14	0.19	0.13	0.22	0.28	0.11	1.30
TiO ₂	0.46	0.67	0.29	0.98	0.89	0.93	0.87	0.82	0.80	0.28
P ₂ O ₅	0.11	0.06	0.03	0.05	0.15	0.11	0.09	0.10	0.13	0.09
MnO	0.25	0.18	0.20	0.20	0.22	0.20	0.21	0.22	0.18	0.05
H ₂ O	1.75	1.48	1.60	1.67	0.98	1.27	1.40	1.35	2.54	0.73
S			tr							NIL
CO ₂	0.09	0.28	0.14	1.28	0.15	0.07	0.11	0.08	0.15	0.12
Less O = S										
TOTAL	100.04	100.01	100.32	99.63	99.76	100.12	100.09	99.92	100.37	100.03
Ni	156	121	70	88	15	47	<1	37	30	
Cr	490	318	464	757	30	230	10	142	90	
FeO*/MgO	0.95	1.58	0.99	1.72	2.15	1.62	2.39	1.95	1.61	2.04

- 82 Basalt, at eastern side of Lynn Lake airport (32-6-483-2). 5% medium grained biotite crystals and aggregates in a very fine grained hornblende matrix.
- 83 Porphyritic pillowed basalt, 2 km northeast of the north end of Motriuk Lake (32-6-690-3). 30% plagioclase phenocrysts and 15% hornblende pseudomorphs in a very fine grained hornblende-rich matrix with 5% quartz amygdaloids.
- 84 Porphyritic diabase, 1.5 km east of the east end of Desieyes Lake (32-7-2130-1). 30% hornblende pseudomorphs after clinopyroxene in a medium grained amphibolite matrix with 5% ilmenite; relict ophitic texture.
- 85 Porphyritic basalt, 4.5 km northeast of Desieyes Lake (32-6-511-1). 25% clinopyroxene phenocrysts (largely altered to hornblende) in a hornblende-epidote matrix with 4% carbonate.
- 86 Porphyritic basalt, 1 km east of the southern extremity of Ralph Lake (32-6-301-2). 15% plagioclase phenocrysts in a recrystallized matrix with medium grained hornblende porphyroblasts and 5% magnetite.
- 87 Sparsely porphyritic basalt, 4.5 km northeast of Desieyes Lake (32-6-511-2). Plagioclase phenocrysts (5%) and hornblende pseudomorphs (3%) in a very fine grained hornblende-rich matrix with 10% epidote and 5% quartz stringers and aggregates.
- 88 Pillowed basalt, at the south end of Ralph Lake (32-6-138-1). 10% plagioclase phenocrysts and quartz amygdaloids in a recrystallized amphibolite matrix.
- 89 Porphyritic basalt, 500 m southeast of the eastern end of Desieyes Lake (32-6-528-1). 20% plagioclase phenocrysts and aggregates and 15% hornblende pseudomorphs after clinopyroxene in a slightly foliated hornblende matrix with 4% ilmenite and minor quartz amygdaloids.
- 90 Porphyritic basalt, southern margin of Lynn Lake airport (32-6-475-2). 15% plagioclase phenocrysts, quartz amygdaloids, and chloritic aggregates in a massive, chlorite-quartz-plagioclase matrix with medium grained hornblende porphyroblasts.

Unit 6

- 91 Porphyritic dacite, 1.5 km east of the east end of Desieyes Lake (32-7-2131-2). Phenocrysts of plagioclase (25%) and quartz (5%) in a well foliated quartz-plagioclase-biotite matrix.

Table A1:
Whole-rock chemical analyses (weight per cent), Ni and Cr (ppm), and description and location of samples. (continued)

	92	93	94	95	96	97	98	99	100	101
SiO ₂	74.40	50.50	50.65	55.85	48.75	49.90	50.05	50.90	52.90	54.85
Al ₂ O ₃	12.73	19.72	18.91	15.60	12.01	16.96	10.49	22.45	18.65	18.84
Fe ₂ O ₃	1.04	1.89	2.77	2.37	2.40	2.46	1.15	1.28	1.62	1.71
FeO	2.51	7.73	8.33	9.19	9.63	9.23	7.14	6.53	7.85	6.80
CaO	2.15	12.24	11.22	6.51	12.64	9.80	10.80	8.08	8.54	7.75
MgO	0.56	4.02	3.08	3.16	8.42	5.97	14.98	3.33	4.49	2.53
Na ₂ O	2.97	1.67	1.69	3.66	2.08	2.15	1.04	3.58	3.40	3.69
K ₂ O	2.21	0.37	0.52	0.19	0.26	0.57	0.20	1.48	0.31	0.58
TiO ₂	0.27	0.36	0.94	1.18	1.65	0.49	0.32	0.85	0.58	0.83
P ₂ O ₅	0.05	0.06	0.08	0.23	0.15	0.03	0.21	0.09	0.11	0.17
MnO	0.07	0.18	0.16	0.22	0.20	0.23	0.19	0.13	0.19	0.18
H ₂ O	0.63	1.13	1.35	1.08	1.57	1.18	2.93	1.27	1.53	1.20
S	NIL		0.01	NIL	0.12	NIL	NIL			tr
CO ₂	0.19	0.45	0.08	0.03	0.38	0.23	0.23	0.09	0.09	0.40
Less O = S					0.05					
TOTAL	99.78	100.32	99.79	99.27	100.31	99.20	100.02	100.04	100.26	99.53
Ni		27	4	4	166	20	408	8	14	6
Cr		46	26	<8	520	26	1660	10	30	16
FeO*/MgO	6.14	2.35	3.32	3.57	1.40	1.92	0.55	2.30	2.07	3.29

Unit 7

- 92 Porphyritic rhyolite, 1.5 km north of the north end of Motriuk Lake (32-7-2067-3). Well foliated quartz-plagioclase-biotite rock with phenocrysts and stringers of quartz and muscovite porphyroblasts.

Unit 4; analyses 93 to 101

- 93 Porphyritic basalt, 1 km south of Stick Lake (32-6-436-1). 30% plagioclase phenocrysts in a massive amphibolite matrix with 3% carbonate.
- 94 Porphyritic basalt, 1 km south of Payne Lake (32-8-5126-1). 35% plagioclase phenocrysts in a very fine grained, gneissoid amphibolite matrix.
- 95 Andesite, 1.25 km south of Payne Lake (32-8-5130-1). Fine grained amphibolite with minor garnet and minor (7%) quartz-feldspathic aggregates, derived from phenocrysts or amygdalae.

Northern belt: unspecified. Includes rocks close to the contact of divisions C and D (analysis 99) and D and E (analysis 98). Analysis 101 is within division C. Analyses 96, 97 and 100 are from the area east of Arbour Lake where volcanic divisions have not been defined.

- 96 Pillowed basalt, 1 km east of Bob Lake (32-8-5180-1). Hornblende-rich variolites at pillow margins are coalescent toward pillow cores. 15% hornblende pseudomorphs and aggregates (after clinopyroxene) in a massive hornblende-epidote matrix. Primary texture well preserved.
- 97 Porphyritic basalt, 500 m north of the west end of Raven Lake (32-8-5198-1). 15% plagioclase phenocrysts and 7% pseudomorph hornblende aggregates in a massive recrystallized matrix of fine-grained quartz and plagioclase with coarser hornblende porphyroblasts.
- 98 Basalt, 1.75 km south of Payne Lake (32-8-5138-1). Massive, fine- to medium-grained hornblende with minor quartz aggregates derived from amygdalae (3%).
- 99 Porphyritic basalt, south end of Eric Lake (32-6-497-1). 25% plagioclase phenocrysts (2 - 5 mm) in a very fine grained matrix of plagioclase and quartz overprinted by medium- to coarse-grained hornblende and biotite (15% each).
- 100 Porphyritic basalt, 1 km northeast of the northern end of Muskeg Lake (32-6-368-1). 20% plagioclase phenocrysts and 3% hornblende crystals in a massive amphibolite matrix.
- 101 Porphyritic andesite, east shore of Margaret Lake (32-6-288-7). 20% plagioclase phenocrysts in a very fine grained quartz-plagioclase matrix overprinted by hornblende porphyroblasts. Contains ilmenite (5%) and irregular quartz aggregates (7%), possibly derived from amygdalae.

Table A1:
Whole-rock chemical analyses (weight per cent), Ni and Cr (ppm), and description and location of samples. (continued)

	102	103	104	105	106	107	108	109	110	111
SiO ₂	46.80	48.70	49.15	49.50	49.90	50.00	50.05	50.40	51.00	52.05
Al ₂ O ₃	16.46	16.63	16.85	14.45	20.47	15.48	18.52	13.15	14.52	17.50
Fe ₂ O ₃	1.57	1.20	1.43	1.55	2.60	2.60	3.00	3.19	1.77	1.48
FeO	10.96	6.97	6.86	7.80	8.05	10.02	8.50	6.91	7.97	8.73
CaO	11.73	12.77	12.10	11.09	10.88	9.01	9.69	10.36	9.07	9.10
MgO	7.03	8.20	8.28	10.27	3.30	6.96	3.31	10.47	8.87	4.43
Na ₂ O	1.79	1.84	2.07	1.86	2.14	2.10	2.87	2.00	2.66	3.13
K ₂ O	0.21	0.62	0.62	0.56	0.36	0.82	0.39	0.13	1.37	0.54
TiO ₂	1.35	0.68	0.72	0.57	0.85	0.86	0.94	0.69	0.82	1.02
P ₂ O ₅	0.11	0.17	0.18	0.13	0.06	0.05	0.08	0.16	0.20	0.26
MnO	0.21	0.16	0.16	0.17	0.19	0.22	0.21	0.20	0.17	0.19
H ₂ O	1.61	1.70	1.84	2.02	1.36	1.25	1.61	2.38	1.55	1.35
S	0.04	0.02	0.01	0.01	0.17	0.01	0.02	0.01	0.01	tr
CO ₂	0.33	0.44	0.14	0.12	0.11	0.18	0.51	0.29	0.05	0.11
Less O ≡ S	0.02	0.01			0.07		0.01			
TOTAL	100.18	100.09	100.41	100.10	100.37	99.56	99.69	100.34	100.03	99.89
Ni	44	38	44	112	< 4	24	< 4	136	118	4
Cr	92	242	220	430	8	52	< 8	734	460	18
FeO*/MgO	1.76	0.98	0.98	0.89	3.15	1.77	3.38	0.94	1.08	2.27

SOUTHERN BELT: GEMMELL LAKE-McVEIGH LAKE SECTION (analyses 102 to 113)

Unit 4

- 102 Sparsely porphyritic basalt, 100 m north of Dutton Lake (32-6-90-1). 10% plagioclase phenocrysts in a strongly foliated hornblende matrix with 8% magnetite and minor quartz stringers.
- 103 Porphyritic basalt, 500 m southwest of Fraser Lake (32-8-5060-3). 30% hornblende pseudomorphs after pyroxene and minor plagioclase phenocrysts (7%) in a fine grained amphibolite matrix. From a 3 m thick unit with possible pillow selva remnants, within greywacke sequence.
- 104 Porphyritic basalt, 600 m southwest of Fraser Lake (32-6-146-2). 25% hornblende pseudomorphs after pyroxene in a fine grained amphibolite matrix. From a 5 m thick extrusive or hypabyssal unit within greywacke sequence.
- 105 Massive, medium grained amphibolite, 750 m southeast of the east end of Fraser Lake (32-6-193-1). From a 1 m thick sill within mafic volcanic breccia.
- 106 Densely porphyritic basalt, southwest shore of Louise Lake (32-6-112-1). 45% plagioclase phenocrysts in a hornblende-rich matrix with 15% quartz aggregates, possibly amygdaloidal.
- 107 Well foliated, fine grained amphibolite, southwest shore of Louise Lake (32-6-110-2).
- 108 Porphyritic basalt, 1 km north of Pool Lake (32-8-5019-1). 30% plagioclase phenocrysts in a massive matrix of very fine grained quartz and plagioclase magnetite (6%) and hornblende porphyroblasts.
- 109 Porphyritic basalt, 500 m east-southeast of Dutton Lake (32-6-117-1). 15% hornblende pseudomorphs after pyroxene, partly altered to chlorite, in a strongly foliated hornblende-rich matrix.
- 110 Porphyritic basalt, 750 m south of Stear Lake (32-8-5082-2). 35% hornblende pseudomorphs after pyroxene in a well foliated matrix of quartz and plagioclase (65%), biotite (20%) and hornblende (15%). From a 5 m thick extrusive or hypabyssal unit associated with feldspathic greywacke.
- 111 Porphyritic basalt, 250 m south of Nail Lake (32-6-59-1). 15% plagioclase phenocrysts in a well foliated amphibolite of very fine grained quartz and plagioclase with hornblende porphyroblasts (0.5 - 1 mm).

Table A1:
Whole-rock chemical analyses (weight per cent), Ni and Cr (ppm), and description and location of samples. (continued)

	112	113	114	115	116	117	118	119	120	121
SiO ₂	53.85	60.00	56.30	50.55	49.15	49.95	52.70	49.45	57.90	45.15
Al ₂ O ₃	15.33	13.77	12.49	10.33	10.01	7.77	11.22	10.49	10.08	7.21
Fe ₂ O ₃	2.73	2.58	0.29	0.83	0.99	1.04	0.99	1.01	1.28	0.54
FeO	10.91	9.31	9.23	10.20	10.97	10.38	10.27	10.43	7.67	10.83
CaO	7.58	5.33	5.43	9.37	10.45	10.48	8.12	12.45	8.41	19.40
MgO	3.62	2.49	10.13	13.37	13.14	14.05	10.34	11.95	7.97	9.52
Na ₂ O	2.57	2.89	3.17	1.62	1.32	0.92	2.59	0.42	3.86	0.15
K ₂ O	0.34	0.46	0.10	0.15	0.23	1.29	0.13	0.22	0.15	0.95
TiO ₂	0.79	1.18	0.94	0.84	1.05	0.81	1.09	0.66	0.88	0.54
P ₂ O ₅	0.17	0.12	0.17	0.14	0.13	0.10	0.16	0.11	0.15	0.11
MnO	0.21	0.26	0.19	0.24	0.25	0.26	0.23	0.22	0.24	0.30
H ₂ O	1.53	1.60	1.31	1.84	1.90	2.08	1.59	1.86	1.16	1.44
S	NIL	0.02	0.02	tr	tr	tr	0.10	0.01	0.08	0.01
CO ₂	0.12	0.29	0.22	0.11	0.04	0.11	0.13	0.26	0.15	3.53
Less O ≡ S		0.01					0.04		0.03	
TOTAL	99.75	100.29	99.98	99.59	99.63	99.24	99.62	99.54	99.95	99.68
Ni	< 6	< 4	32	232	151	180	124	88	106	108
Cr	< 8	< 8	378	1740	1280	1724	724	824	864	1104
FeO*/MgO	3.69	4.67	0.94	0.82	0.90	0.81	1.08	0.95	1.11	1.19

112 Aphyric basalt, 1.5 km southwest of the south end of Eldon Lake (32-6-10-1). Well foliated fine grained amphibolite with quartz stringers and aggregates.

113 Fine grained, gneissoid, quartz-rich amphibolite, southwest shore of Louise Lake (32-6-110-1). Hornblende content approximately 30%.

FOX MINE-WILMOT LAKE AREA

FOX LAKE PORPHYRITIC BASALT (unit 3; analyses 114 to 122)

114 Finely porphyritic basalt, 300 m west of Helen Lake (12-7-632-3), fine grained (0.02 mm) cummingtonite amphibolite with small quartz-amphibole-filled amygdaloids; block in coarsely porphyritic breccia matrix.

115 Finely porphyritic basalt, 330 m west of Helen Lake (12-7-6-629-2), cummingtonite amphibolite, flow-top breccia block.

116 Porphyritic basalt flow, 350 m west of Helen Lake (12-7-630-2), 20% hornblende pseudomorphs after pyroxene phenocrysts in a fine amphibolite matrix.

117 Porphyritic pillowed basalt, 1000 m southwest of Helen Lake (12-7-374-C), cumulate base of differentiated pillow, 50% hornblende pseudomorphs after pyroxene phenocrysts in amphibolite groundmass.

118 Porphyritic pillowed basalt, 1000 m southwest of Helen Lake (12-7-374-A), finely porphyritic top of differentiated pillow, 12% mafic phenocrysts, scattered plagioclase-filled amygdaloids.

119 Porphyritic basalt flow (2 m), 1200 m southwest of Helen Lake (12-7-376-2), patchy hornblende amphibolite with a trace of phlogopite.

120 Porphyritic basalt flow, 600 m north of Wolf Lake (12-7-130-1), 15% hornblende pseudomorphs after pyroxene in a groundmass rich in feathery amphibole.

121 Patchy amphibolite, 400 m northeast of Snake Lake (12-7-53-A), coarse amphibole-diopside amphibolite with biotite-rich "fragments".

Table A1:
Whole-rock chemical analyses (weight per cent), Ni and Cr (ppm), and description and location of samples. (continued)

	122	123	124	125	126	127	128	129	130	131
SiO ₂	47.25	47.60	48.45	60.60	54.80	49.65	53.60	49.90	49.70	67.30
Al ₂ O ₃	7.99	15.30	15.12	14.93	15.72	18.25	16.04	16.72	16.45	14.69
Fe ₂ O ₃	0.81	1.64	1.20	1.72	1.93	1.57	1.67	0.96	1.08	0.93
FeO	10.65	7.45	7.57	5.67	8.97	7.37	8.04	7.77	7.77	3.98
CaO	13.61	12.35	13.79	7.08	8.95	10.41	8.82	10.97	10.34	2.12
MgO	12.97	9.39	8.32	4.69	3.37	6.58	4.65	8.08	8.54	1.64
Na ₂ O	0.41	2.27	2.12	3.37	2.84	3.35	4.05	2.38	2.37	2.48
K ₂ O	0.55	0.26	0.22	0.73	0.66	0.45	0.23	0.76	1.17	4.97
TiO ₂	0.76	0.48	0.45	0.41	1.01	0.41	0.87	0.52	0.57	0.55
P ₂ O ₅	0.14	0.03	0.03	0.07	0.12	0.06	0.11	0.07	0.08	0.11
MnO	0.23	0.21	0.20	0.14	0.20	0.21	0.25	0.19	0.18	0.26
H ₂ O	2.00	1.80	1.28	1.08	1.33	1.46	1.09	1.68	1.41	0.78
S	0.01		0.02	tr	0.03	0.01	0	0.01	0.01	tr
CO ₂	1.89	0.76	1.36	0.17	0.64	0.23	0.57	0.15	0.11	0.11
Less O ≡ S			0.01		0.01					
TOTAL	99.27	99.59	100.12	100.66	100.57	100.08	99.99	100.16	99.78	99.92
Ni	84	74	76	24	6	32	14	48	52	4
Cr	2764	200	224	146	12	134	47	232	240	10
FeO*/MgO	0.88	0.95	1.04	1.54	3.18	1.33	2.05	1.07	1.02	2.94

122 Porphyritic flow-breccia, 100 m north of Wolf Lake (12-7-48). felted mass of amphibole, biotite (5%).

MAFIC VOLCANIC ROCKS: FOX MINE SUCCESSION, LOWER PART (Unit 2; analyses 123, 124)

123 Aphyric basalt flow, 200 m east of Fox Mine (12-9-334). fine grained amphibolite with minor cummingtonite, diopside and calcite, thin carbonate veins near sample site.

124 Aphyric basalt flow, 1200 m north of Wolf Lake (12-7-149). massive fine grained amphibolite with minor calcite veins.

MAFIC AND INTERMEDIATE VOLCANIC ROCKS: FOX MINE SUCCESSION (Unit 4; analyses 125 to 130)

125 Porphyritic basalt/andesite, 350 m southwest of Fox Mine (12-8-147-3). 15% hornblende megacrysts. 5% plagioclase phenocrysts in a fine grained amphibolite groundmass, altered (?).

126 Porphyritic basalt/andesite breccia, 350 m southwest of Fox Mine (12-8-147-B). 20% hornblende megacrysts, 20% plagioclase phenocrysts in a mafic matrix with fine grained amphibolite fragments; porphyroblasts of garnet and hornblende.

127 Porphyritic basalt flow, 300 m southwest of Fox Mine (12-8-146-5). 20% hornblende megacrysts, 15% plagioclase phenocrysts in a fine grained amphibolite groundmass.

128 Intermediate breccia, 300 m southwest of Fox Mine (12-8-146-2). fine grained felsic fragments in a coarse amphibolite groundmass with garnet and amphibole porphyroblasts.

129 Porphyritic basalt flow, 1200 m north of Wolf Lake (12-7-148-2A). 30% hornblende pseudomorphs after pyroxene phenocrysts, rare pyroxene cores, 15% plagioclase phenocrysts in a fine grained amphibolite matrix: middle of thick flow.

130 Porphyritic basalt flow, 1200 m north of Wolf Lake (12-7-148-2B). as 129: margin of flow.

SNAKE LAKE DACITE/RHYOLITE (Units 6, 7; analyses 131 to 139)

131 Massive dacite, southeast end of Snake Lake (12-7-450). elongate aggregates of hornblende-biotite in a fine grained matrix of plagioclase and quartz.

Table A1:
Whole-rock chemical analyses (weight per cent), Ni and Cr (ppm), and description and location of samples. (continued)

	132	133	134	135	136	137	138	139	140	141
SiO ₂	67.85	66.85	66.90	70.95	73.10	69.90	72.45	71.90	51.00	45.25
Al ₂ O ₃	14.12	15.00	14.93	13.56	15.27	12.52	12.10	13.02	16.02	10.42
Fe ₂ O ₃	0.80	0.77	0.94	0.68	0.15	1.68	0.83	0.48	1.30	2.16
FeO	3.34	4.48	4.54	3.67	0.46	5.32	4.44	3.88	14.38	9.97
CaO	3.60	3.22	3.13	1.73	1.95	2.26	2.87	1.42	3.80	10.92
MgO	1.81	1.32	1.19	0.98	0.13	1.32	1.18	1.47	6.14	15.16
Na ₂ O	2.45	2.37	2.23	4.12	5.86	2.79	3.51	5.35	1.79	1.57
K ₂ O	3.74	3.87	4.07	2.53	1.25	2.23	1.09	0.89	1.60	0.17
TiO ₂	0.40	0.59	0.59	0.50	0.29	0.63	0.38	0.33	1.48	0.99
P ₂ O ₅	0.04	0.14	0.13	0.12	0.11	0.14	0.07	0.07	0.16	0.11
MnO	0.07	0.08	0.06	0.11	0	0.09	0.11	0.06	0.19	0.21
H ₂ O	1.00	0.84	1.04	0.61	0.55	1.14	0.85	0.72	1.42	2.42
S	tr	0.01	0.02	0.01	0.09	tr	0.11	0.01	0.07	0.01
CO ₂	0.77	0.40	0.11	0.11	0.40	0.15	0.35	0.46	0.15	0.15
Less O $\equiv$ S			0.01		0.04		0.04			
TOTAL	99.99	99.94	99.87	99.68	99.57	100.17	100.30	100.06	99.47	99.51
Ni	8	4	< 2	< 1	< 2	< 2	< 2	< 3	14	392
Cr	24	10	8	< 5	4	4	< 4	6	60	1244
FeO*/MgO	2.24	3.92	4.53	4.37	4.57	5.23	4.47	2.93		0.79

132 Massive porphyritic dacite, 200 m east of Snake Lake (12-7-454), quartz and hornblende aggregates in a granoblastic matrix.

133 Porphyritic dacite (lapilli tuff?), 100 m north of Wolf Lake (12-7-49), quartz phenocrysts and biotite aggregates in a very fine grained matrix of feldspar and quartz, rare felsic lapilli.

134 Massive dacite, east-Dunphy Lake (12-7-100), biotite clots in a fine matrix of quartz, plagioclase, microcline and biotite: probably base of felsic body.

135 Massive porphyritic dacite/rhyolite, east-Dunphy Lake (12-7-78), feldspar-phyric, finely granoblastic: middle of body.

136 Massive porphyritic rhyolite, 600 m east of east-Dunphy Lake (12-7-94), phenocrysts replaced by plagioclase and plagioclase + quartz + muscovite (after potash feldspar?): east margin (top?) of felsic body.

137 Altered(?) dacite/rhyolite, 200 m southeast of Fox Mine (12-9-332-A), fine grained quartz and feldspar with hornblende and garnet porphyroblasts and rare quartz aggregates (phenocrysts?).

138 Altered(?) rhyolite, 300 m southwest of Fox Mine (12-8-146-1B), fine mosaic of quartz and feldspar with hornblende, cummingtonite and biotite blasts.

139 Rhyolite (tuff?), 400 m north of Snake Lake (12-7-62-1), fine grained quartz, feldspar and biotite with hornblende blasts (0.5 mm).

Unit 9

140 Anthophyllite-garnet schist, 300 m north of Snake Lake (12-8-132).

WILMOT LAKE VOLCANIC ROCKS (IN PROBABLE STRATIGRAPHIC ORDER): Unit 4; analyses 141 to 148

141 Mafic-ultramafic schist, 2000 m northeast of Hassett Lake (12-7-261), hornblende blasts (0.5 mm) in fine grained matrix of amphibole.

Table A1:
Whole-rock chemical analyses (weight per cent), Ni and Cr (ppm), and description and location of samples. (continued)

	142	143	144	145	146	147	148	149	150	151
SiO ₂	52.35	51.15	50.25	46.60	55.05	59.95	47.70	75.30	52.70	52.90
Al ₂ O ₃	14.02	15.49	17.56	13.83	16.37	16.29	13.09	11.00	14.21	14.53
Fe ₂ O ₃	2.54	2.34	2.19	2.24	2.14	1.90	2.31	0.18	1.45	1.91
FeO	9.73	10.18	9.51	11.17	8.76	6.46	9.94	1.89	8.71	10.36
CaO	8.88	10.33	9.98	14.70	8.70	7.78	9.54	4.33	10.4	7.43
MgO	5.80	5.14	3.47	5.51	3.72	2.26	11.72	0.25	5.24	4.51
Na ₂ O	3.41	2.04	2.45	1.32	2.22	2.91	2.39	3.88	3.05	2.75
K ₂ O	0.35	0.23	0.33	0.41	0.41	0.31	0.14	0.34	0.62	1.04
TiO ₂	1.01	1.48	1.52	1.11	1.10	0.95	1.17	0.33	1.08	1.69
P ₂ O ₅	0.09	0.16	0.21	0.12	0.18	0.23	0.19	0.02	0.10	0.26
MnO	0.22	0.21	0.20	0.25	0.20	0.17	0.23	0.12	0.20	0.22
H ₂ O	1.39	1.27	1.32	1.37	0.99	0.79	1.79	0.45	1.13	2.23
S	0.01	0.01	0.01	0.02	0.01	tr	tr	0.01	0.04	0.12
CO ₂	0.17	0.10	0.30	1.38	0.10	0.18	0.10	2.20	1.18	0.44
Less O = S				0.01					0.02	0.05
TOTAL	99.97	100.03	99.30	100.02	99.95	100.18	100.31	100.30	100.09	100.34
Ni	48	28	12	26	6	2	262		32	4
Cr	94	98	25	122	33	16	1050		112	34
FeO*/MgO	2.07	2.39	3.31	2.39	2.87	3.69	1.03	8.23	1.91	2.67

142 Aphyric basalt, 2600 m southwest of Wilmot Lake (12-7-833), fine grained amphibolite.

143 Porphyritic basalt, 2800 m west of Wilmot Lake (12-8-159), 10% hornblende megacrysts and 10% plagioclase phenocrysts, epidote-rich patches near sample.

144 Porphyritic basalt breccia, 2700 m west of Wilmot Lake (12-8-160), 15% plagioclase phenocrysts in fragments and matrix; slightly altered; rare quartz amygdaloids.

145 Porphyritic basaltic flow breccia matrix, 2700 m west of Wilmot Lake (12-8-160-2), hornblende poikiloblasts (2 mm) in fine grained diopside-bearing amphibolite.

146 Porphyritic basalt/andesite, 2700 m west of Wilmot Lake (12-8-161-1), rare quartz-filled amygdaloids in fine grained amphibolite with plagioclase (phenocrysts?).

147 Porphyritic basalt/andesite, 2700 m west of Wilmot Lake (12-8-161-3), rare plagioclase phenocrysts in garnet-bearing amphibolite matrix; epidote alteration nearby.

148 Aphyric basalt, 1600 m northwest of Wilmot Lake (12-7-301), felted green amphibole (up to 0.5 mm) with interstitial plagioclase.

Unit 7

149 Rhyolite tuff, 600 m northwest of Wilmot Lake (12-7-725), 10% quartz phenocrysts (up to 1.2 mm) and biotite aggregates (0.4 mm) in a finely granular groundmass of quartz and feldspar.

LAURIE LAKE-DUNPHY LAKES AREA

TOD LAKE APHYRIC BASALT (Unit 2; analyses 150 to 174)

Outcrop belt 'B' (Fig. 10), in stratigraphic order

150 Pillowed basalt, north end of Tod Lake (12-6-629), fine grained foliated amphibolite; epidote alteration nearby.

151 Small-pillow basalt, island on north end of Tod Lake (12-6-631), foliated amphibolite with sericitized plagioclase (55%) and biotite (2%).

Table A1:
Whole-rock chemical analyses (weight per cent), Ni and Cr (ppm), and description and location of samples. (continued)

	152	153	154	155	156	157	158	159	160	161
SiO ₂	51.45	46.80	52.55	55.95	49.70	48.60	50.10	44.15	51.60	49.00
Al ₂ O ₃	14.20	16.96	13.96	12.45	15.07	15.95	14.60	15.29	14.05	13.32
Fe ₂ O ₃	1.39	0.94	1.78	2.41	1.47	1.43	1.83	2.23	1.58	2.09
FeO	8.87	9.31	10.81	11.44	9.05	8.44	8.70	13.00	9.95	10.36
CaO	9.67	10.33	9.06	7.35	11.29	10.63	11.4	8.07	7.32	12.5
MgO	6.50	3.71	5.21	3.73	8.14	9.42	8.15	11.5	8.92	8.54
Na ₂ O	3.65	4.16	2.72	2.59	2.20	2.11	2.45	2.03	2.83	1.07
K ₂ O	0.48	0.44	0.18	0.48	0.19	0.16	0.18	0.15	0.25	0.16
TiO ₂	1.13	2.56	1.16	1.85	0.92	0.78	0.81	1.20	1.10	1.08
P ₂ O ₅	0.05	0.31	0.12	0.21	0.05	0.04	0.08	0.08	0.09	0.10
MnO	0.22	0.10	0.27	0.25	0.16	0.18	0.18	0.24	0.20	0.20
H ₂ O	1.65	1.44	1.44	1.29	1.26	1.94	1.43	2.29	1.98	1.67
S	0.02	0.01	0.01	0.01	0.02	0.01	0.03	0.04	0.04	0.01
CO ₂	0.86	2.55	0.73	0.17	0.17	0.04	0.15	0.17	0.20	0.15
Less O $\equiv$ S	0.01				0.01		0.01	0.02	0.02	
TOTAL	100.13	99.62	100.00	100.18	99.68	99.73	100.08	100.42	100.09	100.25
Ni	34	14	10	4	146	172	118	133	101	113
Cr	64	16	30	23	416	534	254	290	254	254
FeO*/MgO	1.56	2.74	2.36	3.65	1.27	1.03	1.27	1.31	1.28	1.43

152 Pillowed basalt flow (4 m), island on north end of Tod Lake (12-6-632-5), secondary hornblende up to 0.25 mm long, minor biotite.

Outcrop belt 'B' (Fig. 10)

153 Pillowed basalt, 1400 m southeast of Hatchet Lake (12-7-687), amphibolite with hornblende blast up to 5 mm, 8% calcite.

154 Massive basalt, 1100 m south of Hatchet Lake (12-7-798-1), foliated amphibolite with minor quartz and calcite veins.

155 Pillowed basalt/andesite, 600 m southwest of Hatchet Lake (12-7-807-2), amphibolite with minor garnet porphyroblasts.

Outcrop belt 'C' (Fig. 10)

156 Massive basalt, 500 m north of Fox Mine (12-7-639), fine grained amphibolite with traces of quartz-calcite veins.

157 Massive basalt, 400 m north of Fox Mine (12-7-641-6) amphibolite with hornblende blasts up to 1 mm long, possibly replacing phenocrysts.

Outcrop belt 'D' (Fig. 10), near top of section

158 Pillowed basalt, north end of Tod Lake (12-6-93-1), very fine grained amphibolite, apparently unaltered, jointed sample.

159 Breccia matrix, north end of Tod Lake (12-6-93-3A), foliated amphibolite (tuff-breccia?).

160 Breccia fragments and matrix, north end of Tod Lake (12-6-93-36), amphibolite blasts up to 0.6 mm long.

161 Breccia matrix, north end of Tod Lake (12-6-93-3C), highly foliated amphibolite.

Table A1:
Whole-rock chemical analyses (weight per cent), Ni and Cr (ppm), and description and location of samples. (continued)

	162	163	164	165	166	167	168	169	170	171
SiO ₂	50.30	51.30	49.50	53.20	53.45	50.45	51.95	48.40	48.40	49.45
Al ₂ O ₃	14.31	13.06	14.96	15.15	15.21	17.28	15.16	12.13	9.88	11.39
Fe ₂ O ₃	3.09	2.98	1.53	2.15	2.25	2.08	1.90	2.90	4.20	2.14
FeO	11.24	10.96	10.53	4.86	4.72	5.07	5.53	6.01	5.33	7.05
CaO	9.60	10.7	10.4	10.4	9.91	10.9	8.35	10.4	11.1	11.4
MgO	5.78	5.70	7.82	9.26	8.95	8.36	11.5	14.9	17.1	13.2
Na ₂ O	2.30	1.68	2.13	2.69	3.04	2.22	2.98	1.66	1.01	1.64
K ₂ O	0.22	0.20	0.13	0.18	0.17	0.78	0.15	0.42	0.10	0.77
TiO ₂	1.58	1.45	1.14	0.41	0.40	0.40	0.33	0.47	0.39	0.72
P ₂ O ₅	0.13	0.14	0.06	0.07	0.07	0.05	0.06	0.07	0.24	0.13
MnO	0.19	0.20	0.19	0.13	0.13	0.15	0.14	0.16	0.19	0.18
H ₂ O	1.41	1.50	1.56	1.33	1.12	2.00	1.52	2.35	2.19	1.85
S	0.05	0.03	0.06				0	0	0	0.02
CO ₂	0.24	0.26	0.15	0.06	0.04	0.49	0.04	0.09	0.04	0.13
Less O = S	0.02	0.01	0.02							0.01
TOTAL	100.42	100.15	100.13	99.89	99.46	100.25	99.61	99.96	100.17	100.06
Ni	53	53	120	196	168	126	148	293	600	276
Cr	12	12	328	584	520	380	732	1080	1196	1083
FeO*/MgO	2.43	2.39	1.69	0.73	0.75	0.83	0.63	0.58	0.53	0.68

162 Massive basalt flow, north end of Tod Lake (12-6-93-7A), foliated hornblende amphibolite.

163 Massive basalt flow, north end of Tod Lake (12-6-93-78), foliated hornblende amphibolite.

164 Massive basalt flow, north end of Tod Lake (12-6-630), foliated hornblende amphibolite.

Outcrop belt 'F' (Fig. 10), in stratigraphic order

165 Massive basaltic rock, northeast end of Laurie Lake (12-6-115-G1), massive fine grained amphibolite with scattered acicular amphibole blasts.

166 Basaltic tuff-breccia, northeast end of Laurie Lake (12-6-115-G2), medium grained amphibolite (may be crystal tuff).

167 Foliated amphibolite, northeast end of Laurie Lake (12-6-115-G3), fine grained; sericite along small fractures.

168 Foliated amphibolite, northeast end of Laurie Lake (12-6-115-G4), 2 mm amphibole needles in a fine amphibolite matrix.

169 Mafic schist, northeast end of Laurie Lake (12-6-115-G5), medium grained amphibolite with minor biotite and plagioclase.

170 Mafic schist, northeast end of Laurie Lake (12-6-115-G6), strongly foliated fine grained amphibolite.

Outcrop belt 'F' (Fig. 10), southwestern part

171 Mafic schist, northeast end of Laurie Lake (12-6-40-G1), medium grained amphibolite with diopside (breccia?).

Table A1:
Whole-rock chemical analyses (weight per cent), Ni and Cr (ppm), and description and location of samples. (continued)

	172	173	174	175	176	177	178	179	180	181
SiO ₂	51.50	49.20	52.20	48.30	49.15	49.20	44.20	42.45	48.15	50.25
Al ₂ O ₃	13.96	11.45	15.30	13.79	14.29	14.12	10.30	10.27	15.15	15.86
Fe ₂ O ₃	1.84	1.48	2.62	2.17	2.39	2.05	3.32	3.72	1.98	1.92
FeO	6.78	7.81	5.03	10.38	10.15	10.07	9.72	9.88	8.24	7.13
CaO	9.75	11.2	10.5	9.08	10.5	10.4	7.77	7.09	10.7	11.7
MgO	10.1	14.1	9.05	10.6	8.07	8.69	19.4	20.7	10.5	7.79
Na ₂ O	3.17	1.74	2.57	2.11	2.10	2.27	0.62	0.52	2.48	2.93
K ₂ O	0.35	0.28	0.24	0.19	0.25	0.24	0.07	0.03	0.30	0.36
TiO ₂	0.87	0.62	0.47	0.96	1.12	0.94	0.51	0.45	0.65	0.68
P ₂ O ₅	0.13	0.07	0.13	0.09	0.09	0.08	0.06	0.05	0.05	0.04
MnO	0.17	0.18	0.15	0.19	0.20	0.19	0.20	0.18	0.16	0.15
H ₂ O	1.63	2.05	1.39	1.96	1.89	1.68	3.55	5.11	1.88	1.46
S	0.02	0	0	0.03	0.03	0.04	0.01	0.06	0.01	0.01
CO ₂	0.11	0.15	0.07	0.17	0.15	0.07	0.44	0.18	0.18	0.40
Less O $\equiv$ S	0.01			0.01	0.01	0.02		0.02		
TOTAL	100.37	100.33	99.72	100.01	100.37	100.02	100.17	100.67	100.43	100.68
Ni	175	420	146	245	117	140	640	800	210	93
Cr	762	1312	480	196	196	290	220	442	494	384
FeO*/MgO	0.84	0.65	0.82	1.28	1.16	1.37	0.66	0.64	0.95	1.14

172 Mafic tuff-breccia, northeast end of Laurie Lake (12-6-628-5) medium grained amphibolite matrix and fragments.

173 Mafic/ultramafic rock, northeast end of Laurie Lake (12-6-628-5B), foliated amphibolite (thin unit similar to breccia matrix of 172), probably porphyritic.

174 Mafic tuff(?), northeast end of Laurie Lake (12-6-111-3), feldspar-phryic with a few mafic fragments; medium grained amphibolite.

GABROIC AND ULTRAMAFIC ROCKS (Unit 15, analyses 175 to 181); outcrop belt 'D'

175 Diabase, north end of Tod Lake (12-6-93-4A), base of sill or thick flow; original grain size of 0.7 mm overgrown with amphibole (0.07 - 1.2 mm).

176 Gabbro, north end of Tod Lake (12-6-93-4B), body of sill (175); medium grained amphibolite.

177 Basalt/diabase, north end of Tod Lake (12-6-93-4C), top of sill (175); fine grained, polygonal jointing.

178 Ultramafic rock, north end of Tod Lake (12-6-93-6A), base of differentiated sill, clinopyroxene-, olivine- and spinel-bearing coarse grained amphibolite.

179 Ultramafic rock, north end of Tod Lake (12-6-93-6B), 1 m above base, in olivine-rich layer; sill 178.

180 Gabbro, north end of Tod Lake (12-6-93-6D), body of differentiated sill (178), coarse grained amphibolite.

181 Gabbro, north end of Tod Lake (12-6-93-6E), top of differentiated sill (178), medium grained amphibolite.

Table A1:
Whole-rock chemical analyses (weight per cent), Ni and Cr (ppm), and description and location of samples. (continued)

	182	183	184	185	186	187	188	189	190	191
SiO ₂	77.90	78.15	75.50	57.70	71.20	60.45	55.80	56.90	50.40	48.80
Al ₂ O ₃	11.88	11.59	12.77	14.83	13.57	14.18	18.06	14.16	14.73	15.85
Fe ₂ O ₃	0.51	0.35	0.52	1.85	0.63	1.40	2.30	3.44	2.25	2.05
FeO	1.12	1.08	1.17	9.58	4.20	7.27	6.29	9.50	8.25	9.56
CaO	3.47	3.68	0.76	3.69	1.59	4.10	5.01	5.55	11.53	10.19
MgO	0.22	0.13	0.49	4.38	1.07	5.47	3.05	1.99	7.88	7.94
Na ₂ O	3.63	3.46	3.49	3.24	4.47	2.96	4.25	5.39	2.05	2.31
K ₂ O	0.33	0.44	3.93	1.23	1.64	1.52	2.84	0.30	0.40	0.37
TiO ₂	0.11	0.10	0.12	1.15	0.46	0.61	0.69	1.17	0.81	0.85
P ₂ O ₅	0.01	0.01	0.02	0.13	0.09	0.09	0.22	0.23	0.13	0.07
MnO	0.05	0.04	0.02	0.10	0.08	0.10	0.15	0.24	0.19	0.19
H ₂ O	0.35	0.25	0.52	1.70	0.61	1.19	1.06	1.14	1.24	1.39
S	0.02	0.01	0	0.11	0.01	0.06	0.02	0.05	0.05	0.03
CO ₂	0.37	0.62	0.18	0.11	0.06	1.10	0.07	0.33	0.15	0.07
Less O ≡ S	0.01			0.04		0.02	0.01	0.02	0.02	0.01
TOTAL	99.96	99.91	99.49	99.76	99.68	99.48	99.80	100.37	100.04	99.66
Ni							14	< 1	84	84
Cr							544	12	504	176
FeO*/MgO	7.16	10.73							1.30	1.44

FELSIC VOLCANIC ROCKS (Unit 7: analyses 182, 183)

182 Felsic tuff(?), island on east side of Laurie Lake (12-6-217-G), finely granular quartz and feldspar, scattered quartz eyes.

183 Felsic tuff(?), island on east side of Laurie Lake (12-6-217-G2), finely granular quartz and feldspar.

SEDIMENTARY ROCKS, TUFF (analyses 184 to 189)

Unit 1

184 Felsic siltstone, entrance of Laurie River into Tod Lake (12-6-96-G1), very fine mosaic of quartz and feldspar with biotite and muscovite.

Unit 9

185 Greywacke, northeast end of Laurie Lake (12-6-10-G1), compositionally graded bed of hornblende-bearing metagreywacke.

186 Greywacke, northeast end of Laurie Lake (12-6-10-G2), quartz-rich bed.

187 Greywacke, northeast end of Laurie Lake (12-6-13-G2), cummingtonite-bearing hornblende metagreywacke.

Unit 4; analyses 188, 189

188 Mafic tuff, 300 m east of east-Dunphy Lake (12-7-236), fine grained, cummingtonite-bearing amphibolite.

189 Intermediate tuff, island in the eastern part of Laurie Lake (12-6-214), weakly layered, quartz-bearing amphibolite.

INTRUSIVE ROCKS

Gabbro (Unit 12; analyses 190 to 194)

190 Gabbro, 600 m southeast of east-Dunphy Lake (12-7-37-1), recrystallized plagioclase (1 mm laths) with ophitic hornblende aggregates, pseudomorphs after pyroxene.

191 Gabbro, 603 m southeast of east-Dunphy Lake (12-7-37-3), coarse (10 mm) relict grain sizes.

Table A1:
Whole-rock chemical analyses (weight per cent), Ni and Cr (ppm), and description and location of samples. (continued)

	192	193	194	195
SiO ₂	49.40	49.65	47.50	64.35
Al ₂ O ₃	15.07	16.15	16.41	16.00
Fe ₂ O ₃	1.97	1.51	1.86	1.22
FeO	9.22	7.93	9.40	2.79
CaO	10.99	11.77	10.85	3.73
MgO	7.75	7.66	8.57	2.38
Na ₂ O	2.27	2.22	2.04	4.60
K ₂ O	0.49	0.33	0.25	2.70
TiO ₂	0.86	0.68	0.84	0.45
P ₂ O ₅	0.13	0.09	0.05	0.18
MnO	0.20	0.17	0.20	0.05
H ₂ O	1.46	1.26	1.35	0.72
S	0.13	0.06	0.01	0.02
CO ₂	0.18	0.15	0.29	0.62
Less O $\equiv$ S	100.14**	99.66**	99.62	99.80
Ni	82	76	100	20
Cr	448	368	92	60
FeO*/MgO	1.42	1.21	1.29	1.63

192 Gabbro, 630 m southeast of east-Dunphy Lake (12-7-71-2), relict plagioclase (1 mm) and secondary hornblende.

193 Gabbro, 632 m southeast of east Dunphy Lake (12-7-71-4) scattered, recrystallized plagioclase megacrysts in coarse amphibolite.

194 Gabbro, 1200 m southeast of east-Dunphy Lake (12-7-30-2) relict ophitic texture, plagioclase (1 mm), hornblende after pyroxene.

QUARTZ DIORITE (Unit 16)

195 Hornblende-biotite-quartz diorite, 500 m southeast of east-Dunphy Lake (12-7-40-1), rare plagioclase phenocrysts (up to 1 mm) in a fine grained groundmass of quartz, plagioclase, biotite and hornblende.

**Total includes Cr O₃

Table A2:
Trace element contents (ppm) in selected Wasekwan Group rocks.

	COCKERAM BASALT			HUGHES BASALT		McVEIGH PORPHYRITIC BASALT				MISKWA BASALT
	1	4	5	8	10	14	15	16	18	19
Nb	3	7	6	8	9	10	5	6	4	5
Zr	64	76	85	88	114	136	110	91	102	53
Sr	283	177	173	298	412	954	769	310	211	191
Rb	12	2	5	4	5	31	31	6	11	—
Pb	—	8	6	5	1	4	8	4	—	—
Ga	25	24	20	27	22	27	26	21	25	23
Zn	100	123	118	76	65	98	95	79	140	90
Ni	58	33	15	75	122	47	72	42	15	38
Cu	153	66	91	31	25	104	68	146	46	72
Ba	327	108	114	78	79	883	674	191	181	48
V	250	361	318	237	265	246	196	262	309	268
Cr	99	21	14	45	168	133	216	169	4	125
Y	24	33	33	26	32	23	19	21	39	20

	HUGHES LAKE CALC-ALKALINE SUITE								
	MISKWA BASALT	BASALT			ANDESITE			DACITE	RHYOLITE
	22	27	28	31	33	35	36	39	43 45
Nb	6	7	7	8	9	7	10	8	14 15
Zr	39	110	94	135	130	128	138	148	108 117
Sr	131	353	326	382	327	357	439	368	55 65
Rb	10	6	25	3	3	15	11	13	44 41
Pb	10	—	4	10	—	—	—	—	9 1
Ga	25	27	22	20	22	22	20	24	23 22
Zn	58	71	66	70	60	85	125	40	97 32
Ni	12	75	66	51	50	29	55	15	3 4
Cu	12	38	23	137	11	55	55	54	10 7
Ba	89	360	197	162	158	331	366	235	1258 743
V	386	169	243	139	152	194	133	143	4 1
Cr	18	98	150	38	52	42	58	68	4 —
Y	24	27	25	25	24	26	25	25	49 54

	NORTHERN BELT DIVISION B								
	KEEWATIN DACITE	BASALT						ANDESITE	
	48	62	64	65	67	68	69	71	72 73
Nb	7	12	4	9	4	7	8	6	8 10
Zr	141	100	98	109	78	86	134	116	118 121
Sr	319	187	350	405	292	215	405	270	416 275
Rb	30	5	4	6	26	22	—	17	8 11
Pb	3	2	4	4	3	5	7	1	9 —
Ga	19	24	26	27	25	24	26	26	26 22
Zn	101	123	93	89	110	82	88	117	76 93
Ni	1	108	4	—	6	11	10	7	3 4
Cu	41	152	88	32	124	111	22	78	93 10
Ba	813	61	86	56	326	256	47	340	89 187
V	63	313	233	118	231	307	160	206	105 134
Cr	8	185	8	7	18	13	20	15	— 26
Y	29	25	27	21	18	26	24	25	29 23

Table A2:
Trace element contents (ppm) in selected Wasekwan Group rocks. (continued)

	DIVISION B		NORTHERN BELT DIVISION D							DIV. E
	ANDESITE	DACITE	BASALT							BASALT
	74	75	80	81	83	84	86	89	90	93
Nb	9	7	5	4	4	5	5	6	7	3
Zr	113	125	46	44	41	23	52	59	73	38
Sr	295	261	200	223	198	116	226	123	187	256
Rb	4	20	—	3	4	1	4	4	2	5
Pb	4	—	—	—	—	3	7	2	6	—
Ga	23	21	23	24	21	14	22	24	22	18
Zn	83	88	83	84	108	66	85	110	81	108
Ni	3	15	19	9	109	68	6	38	21	18
Cu	15	42	107	116	29	61	129	55	72	221
Ba	60	404	45	82	73	17	32	21	33	52
V	99	196	176	251	268	243	254	316	176	219
Cr	12	35	26	15	206	289	30	86	63	33
Y	21	24	14	16	13	9	16	21	19	11

	DIV. E.	N BELT UNSPECIFIED			S BELT	FOX LAKE BASALT			SNAKE DACITE	
	ANDESITE	BASALT			BASALT					
	95	96	98	99	103	116	117	118	131	132
Nb	8	8	10	6	6	8	10	7	10	7
Zr	151	103	71	54	101	65	57	84	150	150
Sr	221	214	71	281	593	126	117	263	106	98
Rb	5	—	3	23	14	6	35	3	71	84
Pb	5	—	—	—	8	9	—	7	6	6
Ga	28	26	19	24	21	21	17	21	24	19
Zn	113	93	122	81	88	100	97	98	39	56
Ni	7	177	421	2	43	150	162	112	4	3
Cu	78	161	9	79	78	54	14	101	14	11
Ba	83	65	48	530	192	121	530	41	1121	548
V	181	319	140	197	183	305	260	239	31	54
Cr	7	337	1233	6	159	844	1167	381	4	3
Y	33	21	15	14	15	20	21	24	25	24

	SNAKE DACITE, RHYOLITE			TOD LAKE BASALT			GEMMELL LAKE RHYOLITE		
	134	135	139	158	163	170	4001-3	4002	4004-3
Nb	11	10	8	7	9	8	16	17	15
Zr	150	149	159	56	104	45	351	354	351
Sr	127	128	135	136	145	44	69	113	81
Rb	76	73	16	2	—	3	29	18	47
Pb	5	2	—	3	—	—	5	—	4
Ga	23	19	21	21	23	17	27	23	23
Zn	64	119	81	89	114	88	48	70	87
Ni	4	1	7	113	48	546	4	9	12
Cu	18	9	13	179	214	43	15	18	13
Ba	816	366	296	41	48	5	1235	430	1048
V	42	33	55	270	438	154	15	24	9
Cr	—	5	3	169	12	781	67	80	90
Y	25	25	40	20	36	16	66	74	77

Table A2:
Trace element contents (ppm) in selected Wasekwan Group rocks. (continued)

	LYNN LAKE RHYOLITE						CARTWRIGHT LAKE RHYOLITE		
	4010-1	4011-1	4012-3	4012-4	4012-8	4013	1787-1	1774-1	1778-1
Nb	13	16	16	14	14	8	13	1	12
Zr	213	237	247	212	200	146	107	106	100
Sr	75	98	79	183	178	226	62	83	71
Rb	54	120	110	61	36	45	41	23	37
Pb	5	16	6	—	5	11	27	4	—
Ga	25	25	26	22	21	19	21	20	19
Zn	271	86	115	62	83	116	53	28	21
Ni	8	4	3	3	4	1	8	5	1
Cu	20	19	9	10	20	12	4	7	3
Ba	870	1585	660	833	470	1197	1236	896	875
V	10	10	10	11	7	11	3	6	—
Cr	48	45	44	46	62	60	74	109	93
Y	38	42	49	40	38	23	52	52	52

Table A3:
Rare earth element, U, Hf, Th and Sc abundances (ppm) in Wasekwan Group rocks.

	4	5	8	10	14	15	27	28	31	35
La	11	13	13	23	24	23	17	33	20	15
Ce	23	29	28	50	46	43	37	76	44	30
Nd	14	18	14	30	26	25	23	42	22	16
Sm	4.1	4.4	3.7	6.5	5.8	5.2	5.1	9.4	5.0	3.9
Eu	1.7	1.7	1.5	2.5	2.0	1.7	1.8	2.8	1.6	1.3
Tb									0.9	0.7
Dy									5.3	4.8
Yb	4	4	3	3	2	2	3	6	2.6	2.7
Lu	0.63	0.57	0.40	0.51	0.31	0.22	0.40	0.93	0.37	0.40
La _N /Sm _N	1.6	1.8	2.1	2.2	2.5	2.7	2.0	2.1	2.4	2.3
Tb _N /Yb _N									1.5	1.1
La _N /Yb _N	1.8	2.1	2.9	5.1	7.9	7.6	3.7	3.6	5.1	3.7
Eu/Eu*	1.1	1.1	1.1	1.2	1.0	1.0	1.0	0.84	1.0	1.0
U	0.2	0.6	0.4	0.6	1.0	0.8	0.7	0.7	1.3	0.8
Hf	2.0	1.3	1.7	1.7	1.0	1.8	1.4	5.5		
Th	0.5	0.8	0.7	0.9	3.2	2.8	1.2	3.5	2.4	2.4
Sc	45	42	31	35	30	39	25	26		
	36	39	42	45	62	67	68	69	73	74
La	20	18	18	19	9.5	8.3	7.0	14	13	10
Ce	41	40	42	45	21	16	19	36	29	24
Nd	22	21	20	28	16	11	12	22	17	14
Sm	4.7	4.6	5.4	7.8	4.8	3.4	3.3	4.6	4.2	3.9
Eu	1.6	1.6	0.7	1.1	1.8	1.4	1.4	1.6	1.4	1.4
Tb	0.8	0.7	1.6	1.7					0.7	0.7
Dy	4.6	4.5	12.0	11.0					4.7	4.2
Yb	2.2	2.4	8.4	6.9	2	2	3	2	2.0	2.1
Lu	0.34	0.34	1.30	0.98	0.29	0.32	0.38	0.39	0.29	0.29
La _N /Sm _N	2.6	2.4	2.0	1.5	1.3	1.4	1.3	1.9	1.9	1.6
Tb _N /Yb _N	1.5	1.2	0.8	1.1					1.5	1.4
La _N /Yb _N	6.0	5.0	1.4	1.8	3.3	2.6	1.5	4.6	4.3	3.1
Eu/Eu*	1.0	1.1	0.33	0.39	1.1	1.2	1.4	1.0	1.0	1.1
U	0.8	1.4	4.0	2.1	0.3	0.4	0.5	1.2	0.9	0.5
Hf					2.5	1.2	2.3	2.9		
Th	2.3	2.7	10.0	6.5	1.0	0.7	0.8	0.9	1.0	1.0
Sc					37	38	43	29		
	80	83	86	89	108	109	117	118	124	129
La	3.9	2.6	5.2	5.1	3.6	6.7	6.9	6.6	2.9	7.0
Ce	8	6	12	10	8	15	16	16	6	13
Nd	6	5	8	8	7	13	11	13	5	8
Sm	1.6	1.6	2.3	2.7	1.8	2.7	2.9	3.9	1.3	2.1
Eu	0.9	0.9	1.1	1.1	0.9	1.0	1.1	1.4	0.5	1.1
Tb										
Dy										
Yb	1	2	2	3	1	2	2	2	1	2
Lu	0.18	0.18	0.29	0.43	0.24	0.27	0.28	0.36	0.13	0.21
La _N /Sm _N	1.5	1.0	1.4	1.2	1.2	1.5	1.5	1.0	1.4	2.0
Tb _N /Yb _N										
La _N /Yb _N	2.6	0.9	1.7	1.1	2.4	2.2	2.3	2.2	1.9	2.3
Eu/Eu*	1.6	1.5	1.3	1.1	1.5	1.0	1.1	1.0	1.1	1.4
U	0.5	0.3	0.2	0.1	0.1	0.3	0.6	0.8	0.9	1.4
Hf	0.9	1.2	0.9	1.4	0.6	1.9	1.5	1.8	1.0	1.0
Th	<0.5	<0.5	<0.5	0.7	<0.5	1.1	1.8	2.8	0.5	0.7
Sc	29	48	44	51	43	36	44	35	53	45

Table A3:
Rare earth element, U, Hf, Th and Sc abundances (ppm) in Wasekwan Group rocks. (continued)

	132	135	142	148	158	170	92	4001-3	4010-1	4012-4
La	25	9	5.5	9.8	3.2	11	14	35	40	37
Ce	50	25	16	21	9	23	31	77	81	76
Nd	25	13	10	15	7	12	16	42	41	40
Sm	5.0	3.0	3.6	3.8	2.3	2.8	3.9	10.0	8.5	8.3
Eu	1.2	1.1	1.3	1.5	1.3	0.9	1.2	1.7	1.9	1.7
Tb	0.7	0.6					0.7	2.2	1.3	1.3
Dy	3.8	3.8					4.7	14.8	8.3	8.1
Yb	2.3	2.3	4	2	2	1	4.6	9.4	4.8	4.9
Lu	0.31	0.34	0.62	0.36	0.35	0.19	0.72	1.50	0.73	0.77
La _N /Sm _N	3.0	1.8	0.9	1.6	0.8	2.4	2.2	2.1	2.9	2.7
Tb _N /Yb _N	1.3	1.1					0.6	1.0	1.1	1.1
La _N /Yb _N	7.2	2.6	0.9	3.2	1.1	7.3	2.0	2.5	5.4	5.0
Eu/Eu*	0.84	1.1	1.0	1.2			0.94	0.48	0.72	0.64
U	2.1	2.2	0.8	0.3	0.1	0.5	1.3	2.2	2.7	2.5
Hf			1.9	2.1	1.5	0.8				
Th	9.0	7.4	0.9	0.7	<0.5	1.7	4.0	5.5	11.0	12.0
Sc			46	36	46	23				
	Normalizing Values ¹									
	4013	503-1	467-1B	619	772-8					
La	20	7	7	7	12	0.315				
Ce	44	16	16	19	29	0.813				
Nd	23	10	10	15	19	0.597				
Sm	5.1	2.7	2.6	4.6	5.4	0.192				
Eu	1.5	0.9	1.4	1.8	1.9	0.0722				
Tb	0.7	0.5	0.5	0.9	1.2	0.047				
Dy	4.7	3.2	3.0	5.5	8.3	0.325				
Yb	2.8	1.9	1.4	2.5	4.9	0.208				
Lu	0.41	0.28	0.20	0.37	0.74	0.0323				
La _N /Sm _N	2.4	1.6	1.6	0.9	1.4					
Tb _N /Yb _N	1.1	1.1	1.5	1.5	1.0					
La _N /Yb _N	4.7	2.4	3.3	1.8	1.6					
Eu/Eu*	1.0	1.0								
U	2.0	0.5	0.1	0.6	0.2					
Hf										
Th	6.3	0.9	0.9	2.0	1.3					
Sc										

¹REE values for Leedy chondrite (Masuda et al., 1973) divided by 1.20. The value for Tb is from Haskin et al. (1968).

Table A4:
Average contents of selected elements in Archean volcanic rocks.

	K ₂ O	Rb	Sr	Ba	Ni	Cr	Zr	TiO ₂	Reference
1. THOLEIITIC BASALTS									
Tholeiitic metabasalt: less than 16.6 per cent Al ₂ O ₃	0.27	6	145	81	98	276		1.32	1
Depleted Archean tholeiite	0.18	4	100	80	225	350	55	1.92	2
Enriched Archean tholeiite	0.32	10	165	90	100	175	100	1.00	2
Canadian Archean basalts	0.31	6	165	98					3
Superior Province	0.33		149	99	162	256	108	1.16	4
Abitibi	0.20		124	110	232	292	82	1.30	5
Abitibi (50% SiO ₂ ; tholeiitic suite)	0.35				105	85		2.25	6
Bulawayo					180	438			7
Hayes River Group	0.27		180	130	124	364		1.04	8
2. THOLEIITIC ANDESITE									
Superior Province	0.86		206	223	107	88	216	1.20	4
Abitibi (60.2% SiO ₂ ; tholeiitic suite)	0.67				45	38		1.29	6
3. CALC-ALKALINE BASALT									
Superior Province	0.54		191	154	131	176	88	0.99	4
Abitibi (48.6% SiO ₂ ; primitive calc-alkaline suite)	0.57				170	108		1.26	6
Bulawayo					129	245			7
4. CALC-ALKALINE ANDESITE, UNCLASSIFIED ANDESITE									
Depleted Archean andesite	0.25	7	129	149	85	175	103	1.10	2
Low-alkali Archean andesite	0.67	22	278	230	70	125	150	0.92	2
High-alkali Archean andesite	1.9	75	580	547	60	88	190	0.65	2
High alumina andesite (54-62% SiO ₂)	0.88	26	184		73	102			1
Superior Province: calc-alkaline	0.98		239	298	112	105	126	0.81	4
Abitibi (57.1% SiO ₂ ; primitive calc-alkaline suite)	0.82				115	70		0.95	6
Abitibi	0.95		173	218	67	89	84	0.82	5
Bulawayo: calc-alkaline					62	69			7
5. RHYOLITE									
Depleted siliceous volcanics: rhyolite	2.0	41	110	480	10	12	30	0.19	2
Undepleted siliceous volcanics: rhyolite	3.0	43	100	750	10	12	350	0.14	2
Superior Province: calc-alkaline rhyolite	2.29		105	487	12	11	171	0.27	4
Abitibi (73.1% SiO ₂ ; primitive calc-alkaline suite)	1.60				60	23		0.59	6

References: 1 Gunn, 1976; 2 Condie, 1976; 3 Jahn et al., 1974; 4 Goodwin, 1977; 5 Goodwin and Smith, 1980; 6 Jolly, 1975; 7 Hawkesworth and O'Nions, 1977; 8 Hubregtse, 1978.

Table A5:
Average contents of selected elements in Cenozoic to Recent volcanic suites.

	K ₂ O	Rb	Sr	Ba	Ni	Cr	Zr	TiO ₂	Reference
Ocean ridge basalts	0.14	1	135	11	100	300	100	1.50	1
Ocean ridge basalt (N-type MORB)	0.13	1	124	12			85	1.55	9
Ocean ridge high-alumina basalt (Amsterdam Island)	0.64	17	324	207	45	51		1.58	2
Inter-arc high-alumina basalt (Parace Vela basin)	0.32	7	178	22	169		69	1.05	3
Marginal basin basalt		5	202	47	71	251			4
Hawaiian tholeiites	0.46	9	340		210	400		2.40	2
Island arc tholeiitic basalt	0.44	5	200	75	30	50	70	0.80	5
Island arc tholeiitic basalt	0.39	5	200	110			22	0.50	9
Island arc high-alumina basalt (New Hebrides)	0.6		380	285	30	80		1.00	6
Island arc high-alumina basalt (Antigua)	0.31	5	212	101	16			0.84	8
Island arc tholeiitic andesite	0.43	6	220	100	20	15	70	1.25	5
Island arc calc-alkaline basalt	1.07	10	330	115	25	40	100	1.05	5
Island arc calc-alkaline basalt	1.04	14	550	300			40	0.78	9
Island arc calc-alkaline andesite	2.04	30	385	270	18	56	110	0.76	5
Island arc calc-alkaline andesite	0.93	31	281	179	29	32		0.74	7
Island arc calc-alkaline andesite (Mariana arc)	0.92	16	367	307	16	38	82	0.76	10
Continental margin andesite	1.87	61	472	450	29	127		0.92	7

References: 1 Condie, 1976; 2 Gunn et al., 1971; 3 Ridley et al., 1973; 4 Tarney et al., 1976; 5 Jakes and White, 1972; 6 Colley and Warden, 1974; 7 Gunn et al., 1974; 8 Gunn and Roobol, 1974; 9 Sun, 1980; 10 Meijer and Reagan, 1981.

Table A6:
Representative analyses of ocean ridge and island arc basalts.

	N-type MORB ¹	"Primitive" island arc tholeiite ²	"Primitive" calc-alkaline basalt ³	Island-arc calc-alkaline basalt ⁴	
SiO ₂	47.79	52.42	49.02	53.35	¹ Normal (or depleted) ridge segment, 29° N Mid-Atlantic Ridge; sample Chain 21-17, Sun et al. (1979)
Al ₂ O ₃	16.77	14.91	16.84	17.24	
Fe ₂ O ₃	10.33	2.30	1.90		
FeO		7.16	7.01	8.65	² "Primitive" (largely unfractionated) island arc tholeiite, Dakataua caldera, Talasea, New Britain; sample 286B, Lowder and Carmichael (1970). Rare earth element abundances reported in Arth (1981).
CaO	10.98	10.84	11.61	11.06	
MgO	10.35	7.42	8.43	5.75	
Na ₂ O	2.46	2.36	2.33	2.54	
K ₂ O	0.07	0.80	0.58	0.61	
TiO ₂	0.87	0.73	0.72	0.74	³ "Primitive" calc-alkaline basalt probably parental to calc-alkaline basalt (below) and basaltic andesite, Zealandia Bank, Mariana arc; sample 57-C, Dixon and Stern (1983).
P ₂ O ₅	0.06	0.17	0.13	0.11	
MnO	0.18	0.18	0.18	0.17	
H ₂ O		0.87	1.30		
LOI	+0.50			0.83	⁴ Calc-alkaline basalt, Sarigan Island, Mariana arc; sample SA-130, Meijer and Reagan (1981).
TOTAL	99.86	100.16	100.05	100.22	
Mg/(Mg + Fe ²⁺)					
Zr	67	61	67	58	
Sr	50	40	51	67	
Rb	114	300	291	335	
Ba	1.0	15	8.69	10.2	
Ni	8	255	114.5	263	
Cr	245	105	96	32	
V	589	305		96	
Y	196	340	271		
Sc	25	20		20.7	
La _N /Yb _N	41			41	
Ce _N /Yb _N	0.23		1.82	1.98	
Ti/Zr	104	1.26	85	66	
Ti/Y	209	109		214	
Zr/Y	2.0	219		3.2	

Table A7:
Element ratios for chondrite, Archean mantle, Archean volcanic rocks, and Cenozoic island arc basalts.

	Ti/Zr	Ti/Y	Zr/Y	Zr/Nb	V/Zr
Chondrite ¹	102	256	2.5	~16	12
Archean mantle ¹	100 - 110	240 - 250	2.3	18	
Archean spinifex-textured peridotite ¹	113	251	2.3	18.4	8.3
Archean high-MgO basalts ¹	~110	240	2.3	~18	6
Archean low-MgO tholeiites ¹	95	270	2.8	~18	3
MORB depleted ²	109	321	2.9	27	
enriched ²	107	366	3.4	9.3	
Island arc tholeiite ²	136	250	1.8	31	
Island arc tholeiite ³	83	249	3.0		
Calc-alkaline basalt ²	116	310	2.7	29	
Calc-alkaline basalt ³	60	261	4.3		
"Least fractionated" island arc basalt, Mariana arc ⁴	61				4.2
"Primitive" calc-alkaline basalt 57-C, Mariana arc ⁵	85				5.3

References: 1 Nesbitt and Sun, 1976; 2 Sun, 1980; 3 Condie, 1976; 4 Dixon and Batiza, 1979; 5 Dixon and Stern, 1983.

ANALYTICAL METHODS AND LABORATORIES

The major and minor elements, Ni and Cr (Table A1) were determined at the Manitoba Mineral Resources Division Analytical Laboratory in Winnipeg. Samples submitted for silicate rock analysis first have the weathering rind cut off and are subsequently crushed into 6 mm fragments. A portion of the crushed material is ground to a fine powder (-200 mesh) in a Spex Shatterbox using a tungsten carbide dish and puck. SiO₂, Al₂O₃, TiO₂ and P₂O₅ were determined by colorimetry whereas Fe₂O₃, FeO, CaO, MgO, Na₂O, K₂O, MnO, Ni and Cr were determined by atomic absorption. H₂O was determined by the Penfield moisture method, and S and CO₂ were measured in an induction furnace.

The trace elements Nb, Zr, Sr, Rb, Ba, Ga, Zn, Ni, Cu, Ba, V, Cr and Y (Table A2) were determined by X-ray fluorescence at Memorial University of Newfoundland in 1979. These elements were corrected for matrix effects by use of the Ag Compton peak.

The rare earth elements La, Ce, Nd, Sm, Eu, Yb and Ly, plus Sc, Hf and Th (Table A3), were determined in the basalts by Nuclear Activation Services Ltd., Hamilton, Ontario, in 1981, by the induced neutron activation analysis (INAA) method. U was determined by delayed neutron counting. Another batch of samples (andesites and rhyolites) was analyzed for the same elements, plus Tb and Dy, at Nuclear Activation Services in 1982.